ENERGY OUTWEST
WEATHERIZATION FIELD GUIDE

Best Practices for the Weatherization Assistance Program

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WEATHERIZATION FIELD MANUAL

Best Practices for the Weatherization Assistance Program

Produced by the Department of Energy – Seattle Regional Office, and Energy OutWest

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1.1 CLIENT HEALTH AND SAFETY

House fires, carbon monoxide poisoning, moisture problems, and lead-paint poisoning are the most important health and safety problems that are related to weatherization work. When these are noted in the home, inform the customer verbally or in writing as appropriate.

- ✔ Inspect the home for fire hazards such as improperly installed electrical equipment, flammable materials stored near combustion appliances, or malfunctioning heating appliances. Discuss the problems with the client, and perform repairs if possible.
- ✔ Test combustion appliances for carbon monoxide production and other related hazards. Test the ambient air for carbon monoxide. Solve the problems causing these hazards.
- ✔ Find moisture problems and discuss them with the client. Never make moisture problems worse.
- ✔ Practice lead-safe weatherization.

NON-WEATHERIZATION HAZARDS

Weatherization specialists should also be aware of home health and safety hazards that aren't directly related to weatherization. Household accidents are reported to kill 24,000 Americans and injure another 3,500,000 each year. Children are at the greatest risk because they spend more time at home and are less aware of danger than adults.

Note these three leading causes of injuries in the home, and help your clients learn to avoid them.

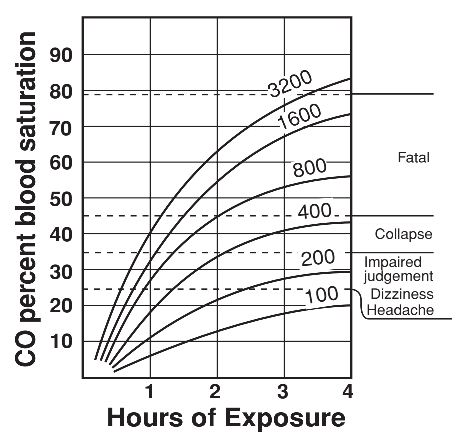
- Falls
- Poisoning by solids and liquids
- Smoke inhalation and burns from fires

Encourage clients to observe these recommendations.

- ✔ Install non-slip grip strips to bathtubs and showers and steps to prevent falls.
- ✔ Make sure that sturdy step stools and ladders are handy where they may be needed for safe climbing.
- ✔ Remove obstacles that could cause slips and falls.
- ✔ Store poisons separately from medicines to prevent accidental poisoning.
- ✔ Repair or replace faulty electrical cords and appliances.
- ✔ Check smoke detectors regularly. Make a fire escape plan for the family.

CARBON MONOXIDE

Carbon monoxide (CO) is released by combustion appliances, automobiles, and cigarettes as a product of incomplete combustion. CO is the largest cause of injury and death in the U.S. from gas poisoning, resulting in more than 500 deaths per year. Additional people are injured or sickened by lower concentrations of the gas. The symptoms of low-level CO exposure are similar to the flu, and may go unnoticed.



Effects of CO: This graphs curves represent different exposure

CO blocks the oxygen-carrying capacity of the blood's hemoglobin, which carries vital oxygen to the tissues. At low concentrations (5-to-50 ppm), CO reduces nerve reaction time and causes mild drowsiness, nausea, and headaches. Higher concentrations (50-to-3000 ppm) lead to severe headaches, vomiting, and even death if the high concentration persists. The effects of CO poisoning are usually reversible, except for exposure to very high levels, which can cause brain damage.

The EPA's suggested maximum 8-hour exposure is 9 ppm in room air. Room levels of CO at or above 9 ppm are usually associated with the use of malfunctioning combustion appliances within the living space, although cigarette smoking or automobile exhaust are also common CO sources.

Causes of carbon monoxide

CO is a common problem in low-income housing, affecting 20% or more of residential buildings in some regions. Offending appliances include: unvented gas space heaters, kerosene space heaters, backdrafting vented space heaters, gas ranges, leaky wood stoves, and automobiles idling in attached garages or near the home. Central furnaces and boilers that backdraft may also lead to high levels of CO, but are less of a problem because they aren't usually located in the living space.

Testing for carbon monoxide

The most common CO-testing instruments are electronic sensors with a digital readout in parts per million (ppm). Follow the manufacturer's recommendations on zeroing the meter—usually by exposing the meter to clean air. CO testers usually need re-calibration every 6 months or so, using factory-specified procedures.

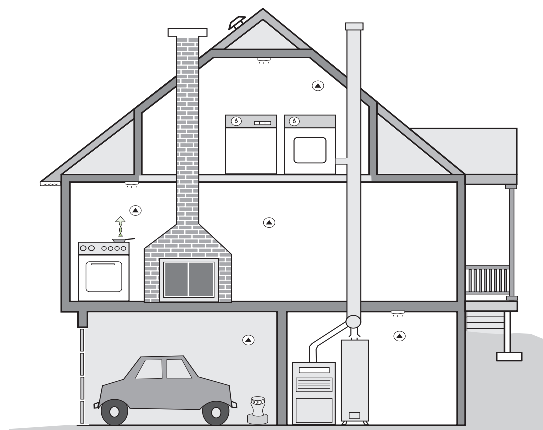
CO is normally tested near the flame or at the exhaust port of the heat exchanger. CO is usually caused by one of the following.

- Overfiring
- Backdrafting of combustion gases smothering the flame
- Flame interference by an object (a pan over a gas burner on a range top, for example)
- Inadequate combustion air
- Flame interference by moving air
- Misalignment of the burner

Heating equipment service should strive to identify and correct these problems.

Smoke and carbon monoxide alarms

All homes should have at least one smoke alarm on each level, including one near the combustion zone and at least one near the bedrooms. Carbon monoxide (CO) alarms are appropriate whenever the CO hazard is considered a likely occurrence.



Smoke and CO alarm locations: Install a smoke alarm on each level of the home, and near combustion appliances. Install CO alarms near combustion appliances such as furnaces, water heaters, and fireplaces.

Customers should be educated about the purpose and features of the alarms and what to do if an alarm sounds. Follow these specifications when installing CO alarms and smoke alarms.

Smoke alarms

Observe these specifications when installing smoke alarms.

✔ Install according to manufacturer's instructions

✔ If mounted on a wall, mount from 4 to 12 inches from the ceiling

- ✔ If mounted on a ceiling, mount at least 6 inches from the nearest wall
- ✔ Connect to a circuit that is energized at all times

Don't install smoke alarms in these cases.

- Within 12 inches of exterior doors and windows
- With an electrical connection to a switched circuit
- With a connection to a ground-fault interrupter circuit (GFCI)

CO alarms

CO alarms should be installed in all homes with unvented space heaters and in all homes where a furnace return air could backdraft a space heater, wood stove, fireplace, or water heater. It is recommended that CO detectors installed in the weatherization program be of the highest quality and have electrochemical sensors. They should have the capability to accurately detect and/or display low levels of carbon monoxide to 10 ppm.

Observe these specifications when installing CO alarms.

- ✔ Install according to the manufacturer's instructions
- ✔ Connect to a circuit that is energized at all times

Don't install CO alarms in these cases.

- In a room that may get too hot or cold for alarm to function properly
- Within 5 feet of a combustion appliance, vent, or chimney
- Within 5 feet of a storage area for vapor-producing chemicals
- Within 12 inches of exterior doors and windows
- Within a furnace closet or room
- With an electrical connection to a switched circuit
- With a connection to a ground-fault interrupter circuit (GFCI)

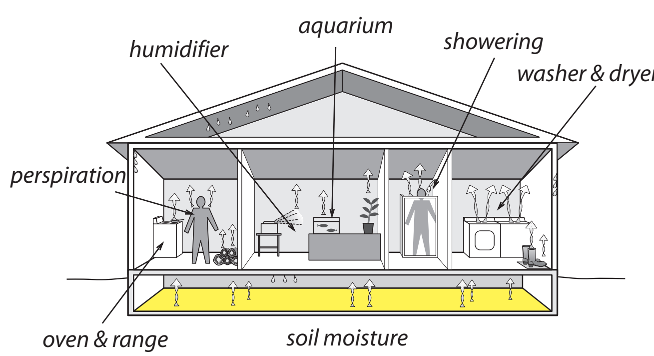
Moisture problems

Moisture causes billions of dollars worth of property damage and high energy bills each year in American homes. Water damages building materials by dissolving glues and mortar, corroding metal, and nurturing pests like mildew, mold and dust mites. These pests, in turn, cause many cases of respiratory distress.

Water reduces the thermal resistance of insulation and other building materials. High humidity also increases air conditioning costs because the air conditioner must remove the moisture from the air to improve comfort.

The most common sources of moisture are leaky roofs and damp foundations. Other critical moisture sources include dryers venting indoors, showers, cooking appliances, and unvented gas appliances like ranges or decorative fireplaces.

Climate is also a major contributor to moisture problems. The more rain, extreme temperatures, and humid weather a region has, the more it's homes are vulnerable to moisture problems.



Moisture sources: Household moisture can often be controlled at the source by informed and motivated occupants.

Reducing sources of moisture is the first priority for solving moisture problems. Next most important are air and vapor barriers to prevent water vapor from migrating through building cavities. Relatively airtight homes may need mechanical ventilation to remove accumulating water vapor.

Table 1.1.1: Moisture sources and their potential contributions

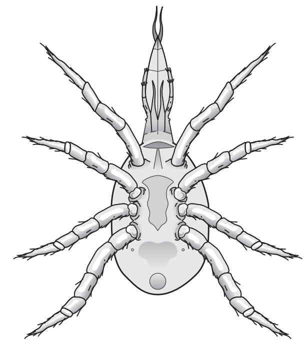
Moisture Source	Potential Amount Pints
Ground moisture	0–105 per day
Unvented combustion space heater	0.5 –20 per hour
Seasonal evaporation from materials	6–19 per day
Dryers venting indoors	4–6 per load
Dishwashing	1–2 per day
Cooking (meals for four)	2–4 per day
Showering	0.5 per shower

Symptoms of moisture problems

Condensation on windows, walls, and other surfaces signals high relative humidity and the need to find and reduce moisture sources. During very cold weather or rapid weather changes, condensation may occur. This occasional condensation isn't a major problem. However, if window condensation is a persistent problem, reduce moisture sources, add insulation, or consider other remedies that lead to warmer interior surfaces. The colder the outdoor temperature, the more likely condensation is to occur. Adding insulation helps eliminate cold areas where water vapor condenses.

Moisture problems arise when the moisture content of building materials reaches a threshold that allows pests like termites, dust mites, rot, and fungus to thrive. Asthma, bronchitis and other respiratory ailments can be exacerbated by moisture problems because mold, mildew, and dust mites are potent allergens.

Rot and wood decay indicate advanced moisture damage. Unlike surface mold and mildew, wood decay fungi penetrate, soften, and weaken wood.



Dust mites: Biological pests create bioaerosols that can cause allergies and asthma.

Peeling, blistering or cracking paint may indicate that moisture is moving through a wall, damaging the paint and possibly the building materials underneath.

Corrosion, oxidation and rust on metal are unmistakable signs that moisture is at work. Deformed wooden surfaces may appear as damp wood swells and then warps and cracks as it dries.

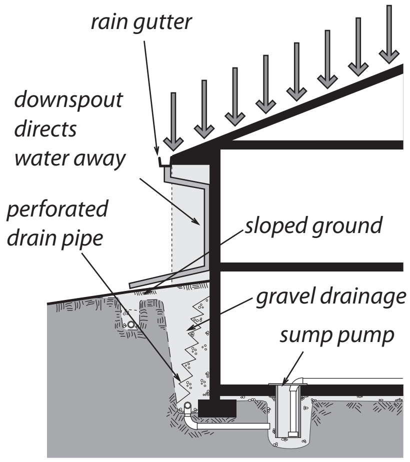
Concrete and masonry efflorescence often indicates excess moisture at the home's foundation. Efflorescence is a white, powdery deposit left by water that moves through masonry and leaves minerals from mortar or the soil behind as it evaporates.

Solutions to moisture problems

Water moves easily as a liquid or vapor from the ground and into porous building materials like concrete and wood. A high groundwater table, for example, can channel moisture into a home faster than anything short of a big roof leak. The most common ground-moisture source is water vapor rising through the soil or liquid water moving up through the soil by capillary action. To prevent this, all crawl spaces should have ground moisture barriers.

A ground moisture barrier is simply a piece of heavy plastic sheeting laid on the ground. Black or clear heavy plastic film works well, but tough cross-linked polyethylene is more durable. The edges should be sealed to the foundation walls with urethane adhesive and/or mechanical fasteners. The seams should be sealed as well.

Rainwater flowing from roofs often plays a major role in dampening foundations. In rainy climates, install rain gutters with downspouts that drain roof water away from the foundation.



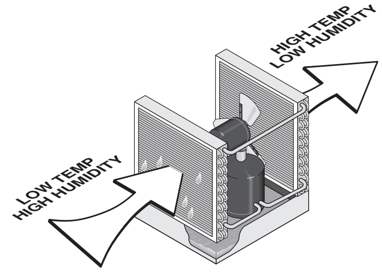
Stopping water intrusion: A variety of measures can protect homes from water intrusion.

A sump pump is the most effective remedy when ground water continually seeps into a basement or crawl space and collects there as standing water. Serious ground-water problems may require excavating and installing drain pipe and gravel to disperse accumulations of groundwater between a home and the underlying soil. These expensive solutions should be reserved for homes with extraordinary moisture problems.

Avoid excessive watering around the home's perimeter. Watering lawns and plants close to the house can dampen its foundation. In wet climates, keep shrubbery away from the foundation, to allow wind circulation near the foundation.

Preventing moisture problems is the best way to guarantee a building's durability and its occupant's respiratory health. Besides the all-important source-reduction strategies listed above, consider the following additional moisture solutions.

- Install or improve air barriers and vapor barriers to prevent air leakage and vapor diffusion from transporting moisture into building cavities. *See section 5.2.*
- Add insulation to the walls, floor, and ceiling of a home to keep the indoor surfaces warmer and less prone to condensation. During cold weather, well-insulated homes can tolerate higher humidity without condensation than can poorly insulated homes.
- Ventilate the home with drier outdoor air to dilute the more humid indoor air. However, passive ventilation is only effective when the outdoor air is drier than the inside air.



Dehumidifiers: In damp climates, dehumidifiers protect many homes from excessive moisture.

- As a last resort, remove moisture from indoor air by cooling the air to below its dew point with compressor-based air conditioning systems in summer and dehumidifiers in winter.

Mechanical ventilation

Ventilation is an important health and safety management system in the most efficient and airtight homes. Ventilation is also important in homes with pollutant sources such as smokers, new furniture, or new carpet. Homes with a natural air-change rate lower than the building tightness limit should have mechanical ventilation systems installed.

Whole-house ventilation system do the best job of providing fresh air and controlling pollutants. These systems may include a heat recovery ventilator to minimize the energy loss from ventilation. But the higher cost of these systems makes them impractical for many homes.

At minimum, all kitchens and bathrooms should be equipped with exhaust fans. They should be installed according to these standards.

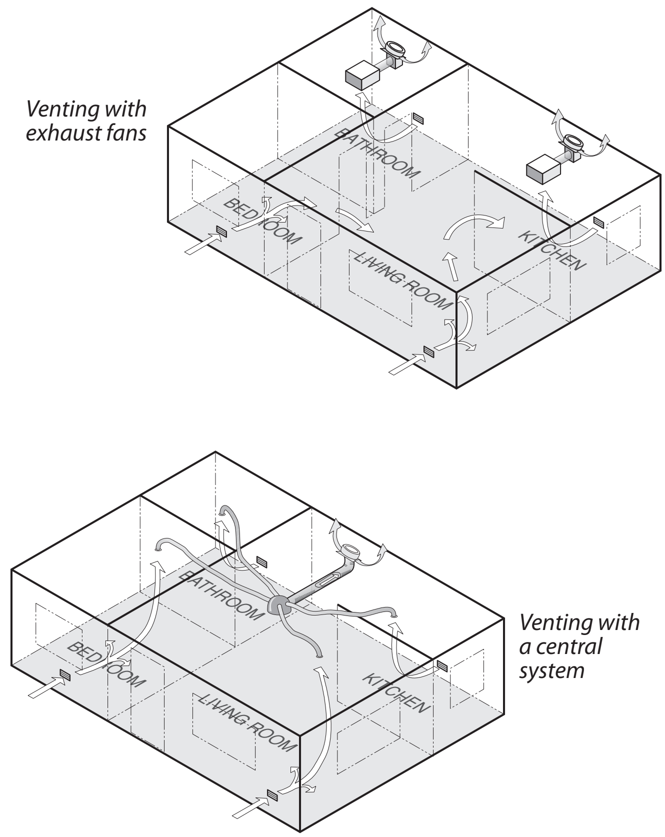
✔ Duct kitchen and bath fans to the outdoors with rigid metal or PVC ducting. Do not use flexible ductwork, and do not run them into crawl spaces or attics.

✔ Install tight-sealing backdraft dampers to prevent heat loss and reduce condensation during the off-cycle. Dampers can be located in the fan housing, in the vent duct, or in the termination fitting at the roof or wall.

- ✔ Don't install re-circulating range hoods. Their filters can't remove important pollutants such as carbon dioxide, carbon monoxide, or water vapor. Duct range hoods to the outdoors.
- ✔ Install high-quality exhaust fans with a low noise rating.

A low noise level is important in encouraging occupants to use exhaust fans. The sound output of exhaust equipment is rated in sones, and these ratings vary from about 5 sones for the noisiest residential exhaust fans to about 0.5 sones for the quietest fans. Choosing an ENERGY STAR® labelled exhaust fan will ensure quiet, long-lasting quality equipment. The success of spot ventilation and whole-house ventilation depends on how much noise the fan makes. Occupants may not use the fans or may disconnect automatic controls if the fans are too noisy.

Exhaust fans can be used to provide whole-house ventilation if high-quality continuous-duty equipment is installed. Under this type of exhaust-only ventilation, outdoor make-up air enters the home through the un-planned pathways in the home's shell. Manual switches, dehumidistats, and/or timers are used to control the fan.



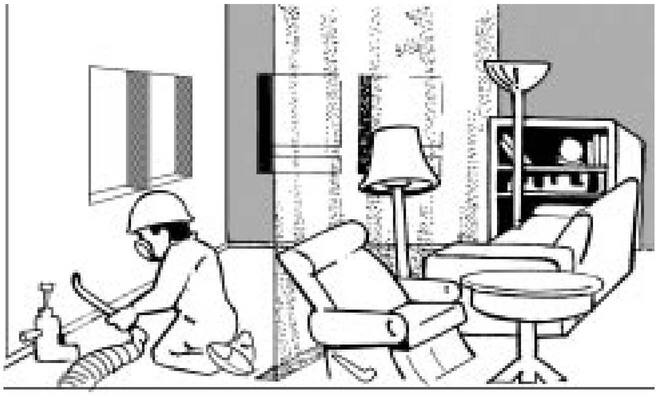
Whole-house ventilation: Whole-house ventilation can be achieved with individual exhaust fans or with a central exhaust venting system.

LEAD-SAFE WEATHERIZATION

Lead-safe weatherization (LSW) is a group of safe practices used by weatherization technicians when they suspect or confirm the presence of lead paint. LSW practices focus on rigorous dust-prevention and housekeeping precautions. Lead-safe weatherization is required when workers will disturb painted surfaces by cutting, scraping, drilling, or other dust-creating activities.

Lead dust is dangerous because it damages the neurological systems of people who ingest it. Children are more vulnerable than adults because of their common hand-to-mouth behavior.

Lead paint was commonly used in homes built before it was outlawed in 1978. Technicians working on these older homes should either assume the presence of lead paint, or, if they believe no lead paint is present, perform tests to rule out its presence.



Protective tarp: Protect clients and their belongings with disposable plastic sheeting when drilling, scraping, cutting, or blowing insulation.

Weatherization activities that could disturb lead paint and create lead dust include the following.

- Glazing, weatherstripping, or replacing windows.
- Weatherstripping, repairing, or replacing doors.
- Drilling holes in the interior of the home for installing insulation.
- Removing trim or cutting through walls or ceilings to seal air leaks, install ducts, replace windows, etc.
- Removing siding for installing insulation.

When engaging in the above activities, take the following precautions.

✔ Wear a tight-fitting respirator to protect yourself from breathing dust or other pollutants.

✔ Confine your work area within the home to the smallest possible floor area. Seal this area off carefully with floor-to-ceiling barriers made of disposable plastic sheeting, sealed at floor and ceiling with tape.

✔ Cover furniture and carpet in the work area with disposable plastic sheeting.

✔ Spray water on the painted surfaces to keep dust out of the air during drilling, cutting, or scraping painted surfaces.

✔ Use a dust-containment system with a HEPA vacuum when drilling holes indoors.

✔ Clean up as you work. Vacuum affected areas with a HEPA vacuum and wet mop these surfaces daily. Don't use the customer's cleaning tools or leave the customer with lead dust to clean up.

✔ Avoid taking lead dust home on clothing, shoes, or tools. Wear boot covers while in the work area, and remove them to avoid tracking dirt from the work area to other parts of the house. Wear disposable coveralls, or vacuum cloth coveralls with a HEPA vacuum before leaving the work area.

✔ Wash thoroughly before eating, drinking, or quitting for the day.

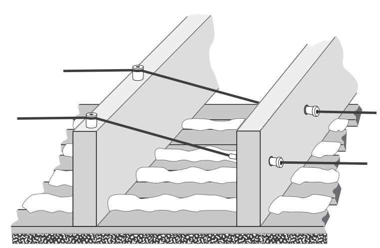
✔ Keep children and pets away from the work area.

For more information refer to the DOE publication *Lead Safe Weatherization, A Training Manual for Weatherization Managers and Crews*.

ELECTRICAL SAFETY

Electrical safety is a basic housing need affecting home weatherization and repair. Observe the following specifications for electrical safety in existing homes.

- Confirm that the electrical system is grounded to either a ground rod or to a water pipe that has an uninterrupted electrical connection to the ground.



Knob-and-Tube Wiring: Prior to insulating around knob-and-tube wiring, barriers must be installed to keep insulation at least 1 inch from the wires.

- Assess the overload protection provided by fuses and circuit breakers. #14 copper or #12 aluminum wiring should be protected by a fuse or breaker rated for no more than 15 amps. #12 copper or #10 aluminum should be protected by a fuse or breaker rated at no more than 20 amps.
- Install S-type fuses where appropriate to prevent occupants from installing oversized fuses.
- Perform a voltage-drop test to assess the size and condition of hidden wiring.
- Ensure that wiring splices are enclosed in metal or plastic electrical boxes that are fitted with cover plates.

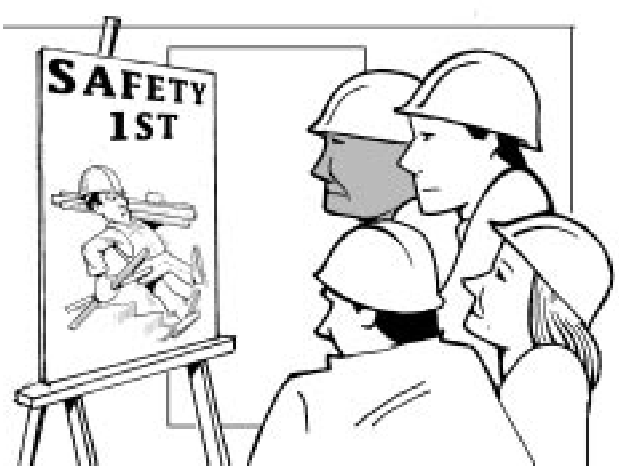
1.2 WORKER HEALTH AND SAFETY

The personal health and safety of each employee is vitally important to every weatherization organization. Injuries are the fourth leading cause of death in the United States, while long-term exposure to toxic materials contributes to sickness, absenteeism, and death of workers. Both of these risk factors are present during weatherization work.

Workplace safety standards have been established by the Occupational Safety and Health Administration (OSHA) and by construction trade organizations; these should be observed by weatherization staff and their contractors. Safety always has priority over other factors affecting weatherization operations.

Some hazards merit the attention of weatherization agencies and their contractors because of their statistical importance. Be aware of these most common workplace hazards.

- Vehicle accidents
- Falls
- Back injuries
- Exposure to hazardous materials
- Electrical hazards
- Repetitive stress injuries



Safety education: Safety meetings are an essential part of a successful safety program.

COMMITMENT TO SAFETY

It is easy to become complacent about jobsite health and safety if it is not continually stressed. Weatherization agencies should do everything possible to create a safe work place by following these practices.

- ✔ Arrange regular health and safety training.
- ✔ Conduct regular safety meetings.
- ✔ Keep equipment in good condition.
- ✔ Observe all state and federal standards relating to worker health and safety.

Safety requires communication and action. To protect themselves from injury and illness, workers are encouraged to recognize hazards, communicate with co-workers and supervisors, and take action to reduce or eliminate hazards.

NEW EMPLOYEES

New hire: New hires are several times more likely to be injured than are experienced workers.

New employees are several times more likely to injure themselves on the job compared to experienced workers. Before their first day on the job, new employees should learn about safety basics such as proper lifting, safe ladder usage, and safe operation of the power tools they will use on the job.

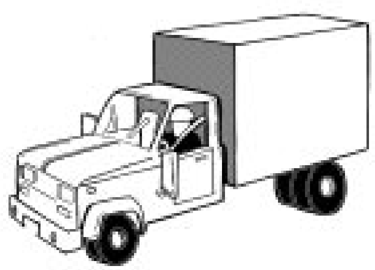
Supervisors must inform new employees about hazardous materials they may encounter on the job. They should be shown the Material Safety Data Sheets (MSDS) required by OSHA for each material.

New employees should be taught to use this common safety equipment.

- Proper clothing
- Gloves
- Respirators
- Safety glasses
- Hearing protectors

Alcohol and drugs should be banned from the job. Staff members should be encouraged to refrain from smoking and to stay physically fit.

Driving



Safe vehicles: Maintain vehicles in good repair. Drivers and passengers should always wear seat belts.

According to the Bureau of Labor Statistics, one-third of all occupational fatalities in the United States occur in motor-vehicle accidents. Staff members should organize their errands and commuting to the job site so as to minimize vehicle travel.

Vehicles should be regularly inspected and repaired if necessary. These safety components are most important.

- Brake system
- Steering system
- Horns
- Headlights
- Directional signals
- Backup lights and signals

Workers should always wear seat belts. When traveling to the job, tools and materials should be properly stowed and secured in the cargo area to prevent shifting.

Lifting and back injuries

Back injuries account for one out of every five workplace injuries. Most of these injuries are to the lower back and are the result of improper lifting.

Workers often injure their backs by lifting heavy or awkward loads improperly or without help. Workers should be instructed in proper lifting techniques such as lifting with the legs and keeping a straight back whenever possible. To avoid back injury, employees are encouraged to get help before trying to lift heavy or awkward loads, to stay in good physical condition, and to control their weight through proper diet and exercise.

Supervisors should identify workers with limited lifting abilities because of weakness or prior injury and instruct them to avoid heavy lifting.

These policies help prevent jobsite injuries.

Awkward loads: Ask for help when moving heavy or awkward loads.

- Redesign work activities: adapt equipment and minimizing awkward movement on the job site.
- Enforce administrative controls: perform strength-testing of workers, set lifting limits, and provide training for all workers on the causes and prevention of back injuries.

Respiratory health

Employees should wear a respirator when working in a dusty environment. Common household dust and construction debris can be full of toxins including lead, asbestos, fiberglass, and chemicals. Drilling, cutting, scraping can stir up toxic dust which may then be inhaled.

Workers should inspect and test their respirators to be sure they have a good fit.

- ✔ Check the straps and face piece to be sure they are soft and free of cracks.
- ✔ Put on the respirator and adjust the straps so they are snug but comfortable.
- ✔ Close the exhalation valve with a hand.
- ✔ Exhale gently and check for leaks around the edges.
- ✔ If there are leaks, adjust or repair the respirator.

Workers with beards, facial scars, and thick temple bars on eyeglasses must take special care to get a good seal.

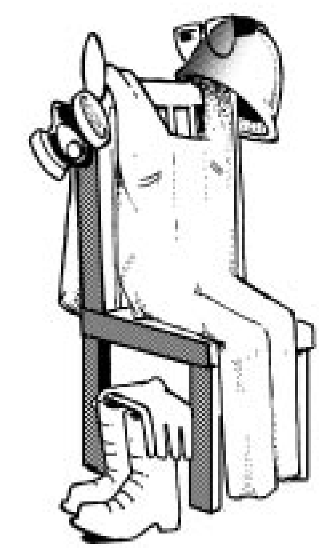
Some airborne hazards require specialized respirator filters. Workers spraying two-part urethane foam, for example, should use a respirator canister designed to filter organic vapors, and they should ventilate the area where the foam is being sprayed. For areas like crawl spaces that are difficult to ventilate, workers should use a supplied-air, positive-pressure respirator.

Workers should be taught how to recognize asbestos insulation that may be installed around older furnaces and boilers. The danger of carrying dust into their own home on their clothing should be stressed as well.

Weatherization workers should control dust in their client's homes by erecting temporary barriers when they are doing work that may release toxic dust. Workers should wear coveralls when entering attics or crawl spaces. Coveralls should be disposable or laundered professionally.

Hazardous materials

Workers' health and safety can be threatened by hazardous materials used on the job. Workers often fail to protect themselves from hazardous materials because they don't recognize and understand their health effects. Breathing hazardous materials, absorbing them through the skin, and coming into eye contact with hazardous materials are common ways workers are affected.



Personal protective equipment: Employees should own and maintain protective equipment to protect themselves from hazardous materials.

OSHA regulations require employers to notify and train employees about hazardous materials used on the job. A Material Safety Data Sheet (MSDS) for every workplace hazardous material should be readily available to employees. Copies of MSDSs are obtained from manufacturers or their distributors. Employees should know where MSDSs are kept and how to interpret them.

Employees should understand how to avoid exposure to hazardous materials used on the job and how to clean up chemical spills. Employees should be instructed to use the appropriate protective equipment that is recommended by the MSDS.

FALLS

Falls off ladders and stairs cause 13% of workplace injuries according to the National Safety Council. Falls from the same elevation such as slips and trips account for approximately 7% of workplace injuries.

Ladders: Ladders are the most dangerous tools on the job.

Broken ladders, and ladders that slip because they haven't been anchored properly, are both major causes of on-the-job falls. Step ladders, for instance, are often used for work that is too far off the ground, forcing workers to stand on the top step or to reach too far.

OSHA regulations include these important guidelines for ladder use.

- ✔ All ladders should be kept in good repair, and should be replaced if they have missing steps or cracked side-rails.
- ✔ Broken ladders should be removed from the equipment storage area.
- ✔ Extension ladders should be set to extend at least three feet above the area they access.
- ✔ Ladders shouldn't have a pitch steeper than four feet of rise for each foot the base is away from the building.
- ✔ Ladders must be blocked or tied firmly in place at the top and bottom if the above rule cannot be observed.
- ✔ Metal ladders should not be used where they may come in contact with electrical conductors.
- ✔ Ladders must be maintained free of oil, grease, and other slipping hazards.
- ✔ Ladders must not be loaded beyond the maximum load for which they were built.
- ✔ Workers should avoid carrying heavy loads up ladders and operating power tools from ladders.

Scaffolding must be used when working aboveground for sustained time periods. Scaffolds should be built plumb and level. Each leg should be stabilized so that it supports equal weight as other legs. This is especially important on unlevel ground. Planks should be secured to the structure and handrails provided on the sides and ends of the walkway.

Good housekeeping: Good housekeeping is essential to protect workers and clients alike from falls.

Workplaces should be policed regularly to remove slipping and tripping hazards. Workers carrying loads should establish a debris-free walkway.

Tool safety

The tools used in construction work are dangerous if used improperly. About 90,000 people hurt themselves with hand tools each year. One moment of inattention can cause an injury that can change a worker's life.

Electrical safety: Cords should be maintained in good condition. Special ground-fault-interrupter cords or outlets should be used in wet conditions.

These basic safety rules can reduce the hazards of using hand and power tools.

- ✔ Use the right tool for the job.
- ✔ Inspect tools for damage before using them.
- ✔ Keep all tools in good condition with regular maintenance.
- ✔ Operate tools according to the manufacturer's instructions.
- ✔ Use appropriate personal protective equipment.
- ✔ Use ground-fault-interrupter outlets or extension cords.

Repetitive stress injuries

Repetitive stress injuries are caused by over-working certain parts of your body. Poor body posture, such as reaching above your head when operating a power drill, can encourage these injuries. Good work habits help prevent this type of injury.

- ✔ Use a comfortable arm and hand posture when operating tools for a long period of time.
- ✔ Change the angle and location of your work surface throughout the day.
- ✔ Mix your difficult tasks with easier ones.
- ✔ Carry smaller loads.
- ✔ Take short rest breaks periodically, and stretch any tight muscles during this time.

When you purchase hand and power tools, look for models with ergonomic designs that place less stress on your body.

SECTION 2 - DIAGNOSTIC TESTING

SUBJECTS COVERED IN THIS SECTION

2.1 HEATING EQUIPMENT TESTS

Energy-auditing has a logical sequence of steps. Decisions about which measures to install are determined by diagnostic testing, visual inspection, practical considerations, and the guidelines established by priority lists or energy-auditing programs.

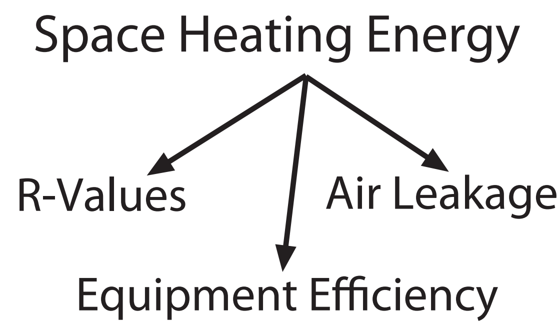
Health and safety issues should always take precedent over efficiency measures if installing measures could jeopardize the occupants or their home.

GAS APPLIANCE ASSESSMENT

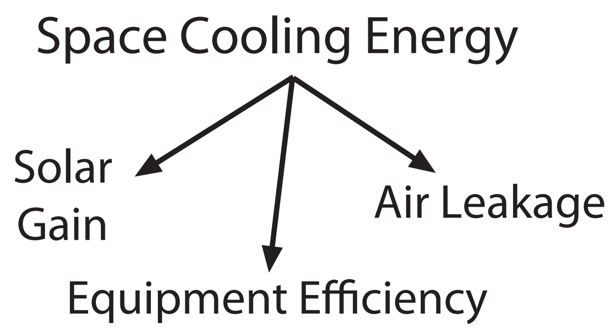
Gas burners should be inspected and maintained every 2 to 4 years. These following specifications apply to gas furnaces, boilers, water heaters, and space heaters.

Perform the following inspection procedures and maintenance practices on all gas-fired furnaces, boilers, water heaters, and space heaters, as necessary. The goal of these measures is to reduce carbon monoxide (CO), stabilize flame, and verify the operation of safety controls.

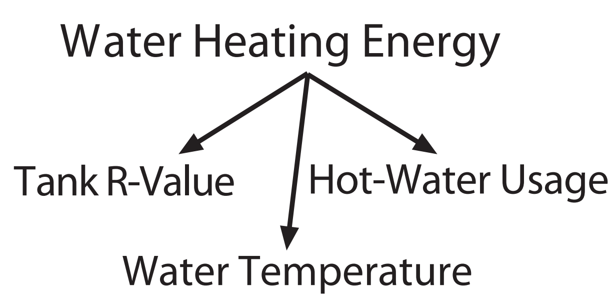
- ✔ Look for soot, melted wire insulation, and rust in the burner and manifold area outside the fire box. These signs indicate flame roll-out, combustion gas spillage, and CO production. *See section 3.1.*
- ✔ Inspect the burners for dust, debris, misalignment, flame-impingement, and other flame-interference problems. Clean, vacuum, and adjust as needed.
- ✔ Inspect the heat exchanger for leaks. *See "Inspecting furnace heat exchangers" in this section.*
- ✔ Furnaces and boilers should have dedicated circuits with fused disconnects. Assure that all 120-volt wiring connections are enclosed in covered electrical boxes.
- ✔ Determine that pilot is burning (if equipped) and that main burner ignition is satisfactory.



Heating energy waste: Heating energy waste fits into three categories. The challenge to reducing heating costs is finding the largest pockets of energy waste and spending resources on the major problems.



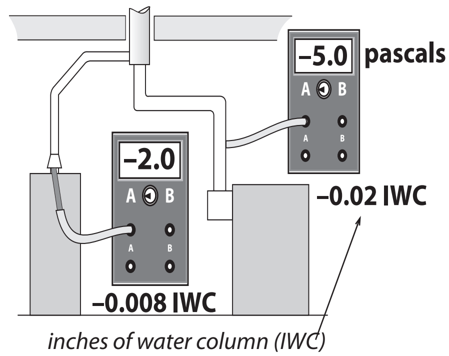
Cooling energy waste: Controlling cooling costs depends less on shell insulation improvements, and more on reducing solar gain.



Water-heating energy waste: The challenge to reducing water-heating costs is ensuring that all three waste categories have been improved.

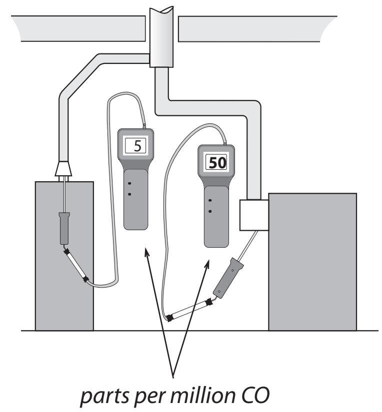
- ✔ Sample the undiluted combustion gases with a calibrated flue-gas analyzer during operation. Carbon monoxide should be less than 100 parts per million (ppm).
- ✔ Test pilot-safety control for complete gas valve shutoff when pilot is extinguished.

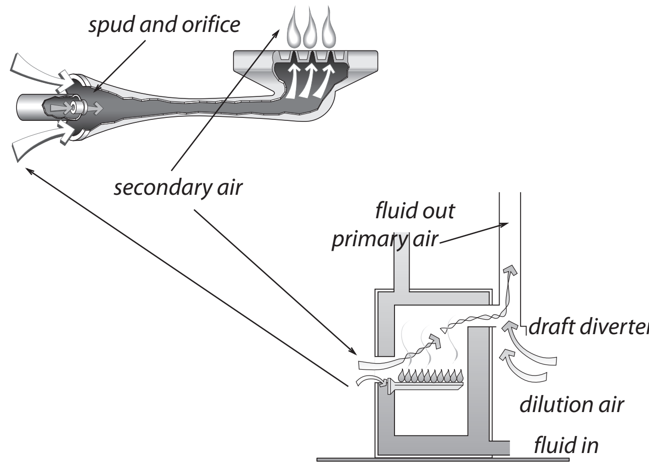
- ✔ Check the thermostat's heat-anticipator setting. The thermostat's heat-anticipator setting should match the measured current in the 24-volt control circuit.
- ✔ Check venting system for proper size and pitch. *See section 3.2.*
- ✔ Check venting system for obstructions, blockages, or leaks.
- ✔ Measure chimney draft downstream of the draft diverter and check for spillage. *See section 3.1.*
- ✔ Test to ensure that the high-limit control extinguishes the burner before furnace temperature rises to 200° F.
- ✔ Measure gas input, and observe flame characteristics if soot, CO, or other combustion problems are present.
- ✔ Open a window while testing for CO to see if CO is reduced by increasing combustion air. *See section 3.1.*



Measuring draft: Measure chimney draft *downstream* of the draft diverter.

Sampling combustion gases: Sample combustion gases at the exhaust vent of the appliance *before* dilution air mixes with the gases.





Atmospheric, open-combustion gas burners: Combustion air comes from indoors in open-combustion appliances. These burners use the heat of the flame to pull combustion air into the burner. Dilution air, entering at the draft diverter, prevents over-fire draft from becoming excessive.

Table 2.1.1: Combustion Standards for Gas Furnaces

Performance Indicator	SSE 70+	SSE 80+	SSE 90+
Combustion-zone pressure (Pa)	–4	–5	–10
Carbon monoxide (CO) (ppm)	≤ 100	≤ 100	≤ 100
Stack temperature (°F)	350°–475°	325°–450°	≤ 120°
Heat rise (°F)	40–70°*	40–70°*	30–70°*
Oxygen (%O2)	5–10%	4–9%	4–9%
Gas pressure Inches (IWC)	3.2–3.8*	3.2–3.8*	3.2–3.8*
Steady-state efficiency (SSE) (%)	72–78%	78–82%	92–97%
Draft (Pa)	–5	–5	+25–60
* pmi = per manufacturer's instructions			

Proceed with burner maintenance and adjustment when:

- CO is greater than 100 ppm.
- Visual indicators of soot or flame roll-out exist.
- Burners are visibly dirty.
- Measured draft is inadequate. *See section 3.1.*
- The appliance has not been serviced for two years or more.

Gas-burner maintenance includes the following measures.

✔ Remove causes of CO and soot, such as over-firing, closed primary air intake, flame impingement, and lack of combustion air.

✔ Remove dirt, rust, and other debris that may be interfering with the burners. Clean the heat exchanger, if necessary.

✔ Take action to improve draft, if inadequate because of improper venting, obstructed chimney, leaky chimney, or depressurization. *See section 3.1.*

✔ Seal leaks in vent connectors and chimneys.

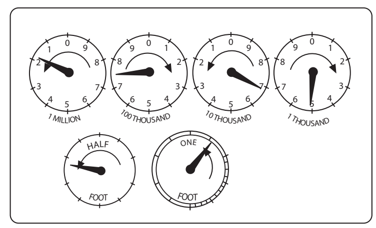
✔ Adjust gas input if combustion testing indicates overfiring or underfiring.

Table 2.1.2: Minimum Worst-Case Draft for Gas Appliances

	Outdoor Temperature (Degrees F)				
Appliance	**<20**	**21-40**	**41-60**	**61-80**	**>80**
Gas-fired furnace, boiler, or water heater with atmospheric chimney	–5 Pa. –0.02 IWC	– 4 Pa. –0.016 IWC	–3 Pa. –0.012 IWC	–2 Pa. –0.008 IWC	–1 Pa. –0.004 IWC

Measuring BTU input on natural gas appliances

Use the following procedure when it's necessary to measure the input of a natural gas appliance.



Gas meter dial: Use the number of seconds per revolution of the one-foot dial and the table on the following page to find the appliance's input.

1. Turn off all gas combustion appliances such as water heaters, dryers, cook stoves, and space heaters that are connected to the meter you are timing, except for the appliance you wish to test.
2. Fire the unit being tested, and watch the dials of the gas meter.

Table 2.1.3: Input in thousands of Btu/hr for 1000 Btu/cu. ft. gas

Seconds per Revolution	Size of Meter Dial			Seconds per Revolution	Size of Meter Dial			Seconds per Revolution	Size of Meter Dial		
	1/2 cu. ft.	1 cu. ft.	2 cu. ft.		1/2 cu. ft.	1 cu. ft.	2 cu. ft.		1/2 cu. ft.	1 cu. ft.	2 cu. ft.
15	120	240	480	40	45	90	180	70	26	51	103
16	112	225	450	41	44	88	176	72	25	50	100
17	106	212	424	42	43	86	172	74	24	48	97
18	100	200	400	43	42	84	167	76	24	47	95
19	95	189	379	44	41	82	164	78	23	46	92
20	90	180	360	45	40	80	160	80	22	45	90
21	86	171	343	46	39	78	157	82	22	44	88
22	82	164	327	47	38	77	153	84	21	43	86
23	78	157	313	48	37	75	150	86	21	42	84
24	75	150	300	49	37	73	147	88	20	41	82
25	72	144	288	50	36	72	144	90	20	40	80
26	69	138	277	51	35	71	141	94	19	38	76
27	67	133	267	52	35	69	138	98	18	37	74
28	64	129	257	53	34	68	136	100	18	36	72
29	62	124	248	54	33	67	133	104	17	35	69
30	60	120	240	55	33	65	131	108	17	33	67
31	58	116	232	56	32	64	129	112	16	32	64
32	56	113	225	57	32	63	126	116	15	31	62
33	55	109	218	58	31	62	124	120	15	30	60
34	53	106	212	59	30	61	122	130	14	28	55
35	51	103	206	60	30	60	120	140	13	26	51
36	50	100	200	62	29	58	116	150	12	24	48
37	49	97	195	64	29	56	112	160	11	22	45
38	47	95	189	66	29	54	109	170	11	21	42
39	46	92	185	68	28	53	106	180	10	20	40

3. Carefully count how long it takes for one revolution of $^1/_2$, 1, or 2 cubic-foot dial. Find that number of seconds in the table above in the columns marked "Seconds per Revolution." Follow that row across to the right to the correct column for the $^1/_2$, 1, or 2 cubic-foot dial. Note that you must multiply the number in the table by 1000. Record the input in thousands of Btus per hour.
4. If the measured input is higher or lower than input on the name plate by more than 10%, adjust gas pressure up or down within a range of 3.2 to 3.9 IWC until the approximately correct input is achieved.
5. If the measured input is still out of range after adjusting gas pressure to these limits, replace the existing orifices with larger or smaller orifices sized to give the correct input.

Table 2.1.4: Combustion Problems and Possible Solutions

Problem	Possible causes and solutions
Weak draft with CAZ depressurization	Return duct leaks, clothes dryer, exhaust fans, other chimneys. Seal return leaks. Provide make-up air.
Weak draft with no CAZ depressurization	Chimney blocked or leaky or else CAZ is too airtight.
Carbon monoxide	Mixture too rich or too lean. Adjust gas pressure. Check chimney and combustion air for code compliance.
Stack temperature or heat rise too high or low	Adjust fan speed or gas pressure. Improve ducts to increase airflow.
Oxygen too high or low	Adjust gas pressure, but don't increase CO level.

Leak-testing gas piping

Natural gas and propane piping systems may leak at their joints and valves. Find gas leaks with an electronic combustible-gas detector, often called a gas sniffer. A gas sniffer will find all significant gas leaks if used carefully. Remember that natural gas rises from a leak and propane falls, so position the sensor accordingly.

- ✔ Sniff all valves and joints with the gas sniffer.
- ✔ Accurately locate leaks using a non-corrosive bubbling liquid, designed for finding gas leaks.
- ✔ All gas leaks should be repaired.
- ✔ Replace kinked or corroded flexible gas connectors.

Advise the client of the following important operating practices.

- ✔ Never install aluminum foil around a range burner or oven burner.
- ✔ Never use a range burner or gas oven as a space heater.
- ✔ Open a window and turn on the kitchen exhaust fan when using the range or oven.
- ✔ Keep range burners and ovens clean to prevent dirt from interfering with combustion.
- ✔ Burners should display hard blue flames. Yellow or white flames, wavering flames, or noisy flames should be investigated by a trained gas technician.
- ✔ Buy and install a CO detector, and discontinue use of the range and oven if the CO level rises above 25 ppm in ambient air.

OIL APPLIANCE ASSESSMENT

Oil burners require annual maintenance to retain their operational safety and combustion efficiency. Testing for combustion efficiency (steady-state efficiency), draft, carbon monoxide, and smoke should be used to guide and evaluate maintenance. These procedures pertain to oil-fired furnaces, boilers, and water heaters.

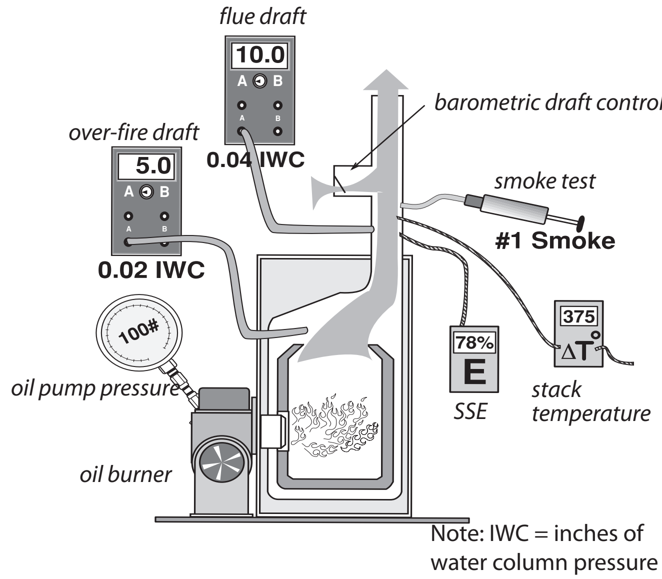
Oil-burner inspection and testing

Use visual inspection and combustion testing to evaluate oil burner operation. An oil burner passing visual inspection and giving good test results may need no maintenance. If the test results are fair, adjustments may be necessary. Unsatisfactory test results may indicate the need to replace the burner or the entire heating unit.

Follow these steps to achieve a minimum standard for oil-burner safety and efficiency.

- ✔ Inspect burner and appliance for signs of soot, overheating, fire hazards, corrosion, or wiring problems.
- ✔ Verify that all oil-fired heaters are equipped with a barometric draft control, unless they have high-static burners or are mobile home furnaces.
- ✔ Each oil furnace or boiler should have a dedicated electrical circuit. Assure that all 120-volt wiring connections are enclosed in covered electrical boxes.
- ✔ Inspect fuel lines and storage tanks for leaks.

- ✔ Inspect heat exchanger and combustion chamber for cracks, corrosion, or soot buildup.
- ✔ Check to see if flame ignition is instantaneous or delayed. Flame ignition should be instantaneous, except for pre-purge units where the blower runs for a while before ignition.
- ✔ Sample undiluted flue gases with a smoke tester, following the smoke-tester instructions. Compare the smoke smudge left by the gases on the filter paper with the manufacturer's smoke-spot scale to determine smoke number.
- ✔ Analyze the flue gas for O_2 or CO_2, temperature, CO, and steady-state efficiency (SSE). Sample undiluted flue gases between the barometric draft control and the appliance.
- ✔ Measure flue draft between the appliance and barometric draft control and over-fire draft over the fire inside the firebox.
- ✔ Measure high-limit shut-off temperature and adjust or replace the high-limit control if the shut-off temperature is more than 250° F for furnaces or 180° F for hot-water boilers.
- ✔ Measure oil-pump pressure, and adjust to manufacturer's specifications if necessary.
- ✔ Measure transformer voltage, and adjust to manufacturer's specifications if necessary.
- ✔ Assure that barometric draft controls are mounted plumb and level and that the damper swings freely.
- ✔ Time the CAD cell control or stack control to verify that the burner will shut off, within 45 seconds, when the cad cell is blocked from seeing the flame.

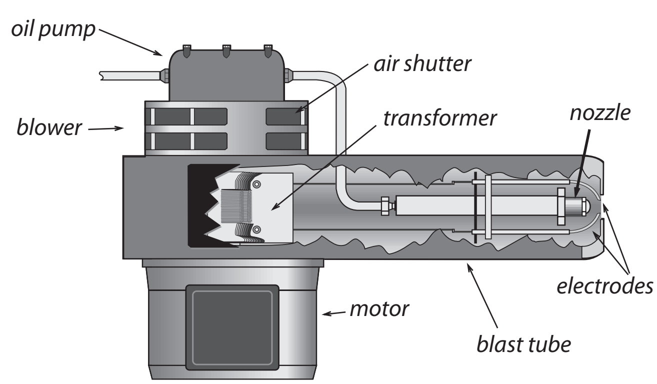


Measuring oil-burner performance: To measure oil-burning performance indicators, a manometer, flue-gas analyzer, smoke tester, and pressure gauge are required.

Oil burner maintenance and adjustment

After evaluating the oil burner's initial operation, perform some or all of the following maintenance tasks as needed to optimize safety and efficiency as part of weatherization service.

- ✔ Verify correct flame-sensor operation.
- ✔ Replace burner nozzle after matching the nozzle size to the home's heat-load requirements.
- ✔ Clean the burner's blower wheel.
- ✔ Replace oil filter(s).



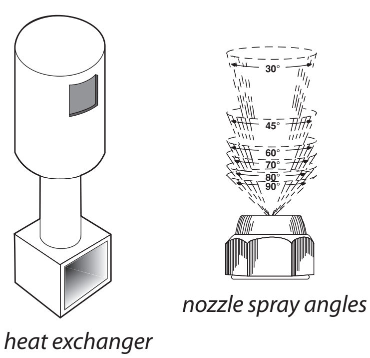
Oil burner: Performance and efficiency will deteriorate over time if neglected. Annual maintenance is recommended.

- ✔ Clean or replace air filter.

- ✔ Remove soot and sludge from combustion chamber.
- ✔ Remove soot from heat exchange surfaces.
- ✔ Clean dust, dirt, and grease from the burner assembly.
- ✔ Set oil pump to correct pressure.
- ✔ Adjust air shutter to achieve oxygen and smoke values. *See section 3.1.*
- ✔ Adjust barometric damper for flue draft of 5–10 pascals or 0.02-to-0.04 IWC (before barometric damper).
- ✔ Adjust gap between electrodes to manufacturer's specifications.
- ✔ Repair the ceramic combustion chamber, or replace it if necessary.

After these maintenance procedures, the technician performs the diagnostic tests described previously to evaluate improvement made by the maintenance procedures and to determine if fine-tuning is required.

Upgrading to flame-retention burners



Oil spray pattern and combustion chamber: Matching the burner's spray pattern to the combustion chamber is important to retrofit applications.

A flame-retention burner is a newer type of oil burner that gives a higher combustion efficiency by swirling the mist or oil and air to produce better mixing. Flame-retention burners, which have been available for more than 20 years, waste less heat and have steady-state efficiency (SSE) of 80% or slightly more. Replacing an old-style burner with a flame-retention model may be cost-effective if the existing SSE is less than 75%. Flame-retention-burner motors run at 3450 rpm and older oil burners run at 1725 rpm motor speed. Looking for the nameplate motor speed can help you discriminate between the flame-retention burners and their older cousins.

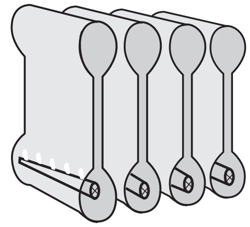
If a furnace or boiler has a sound heat exchanger but the oil burner is inefficient or unserviceable, the burner may be replaced by a newer flame-retention burner. The new burner must be tested for efficient and safe operation as described previously.

- Size the burner and nozzle to match the building's heat load, making adjustments for new insulation and air sealing done during weatherization. (With steam heating, size the burner to existing radiation surface area.)
- Install new combustion chamber, choosing one that fits the size and shape of the burner flame. Or, change nozzles on the new burner to produce a flame that fits an existing combustion chamber that is still in good condition. Either way, the flame must fill the combustion chamber without impinging to the point where soot is formed.

Inspecting furnace heat exchangers

Leaks in heat exchangers are a common problem, causing the flue gases to mix with house air. Ask clients about respiratory problems, flue-like symptoms, and smells in the house when the heat is on. Also, check around supply registers for signs of soot, especially with oil heating. All furnace heat exchangers should be inspected as part of weatherization. Consider using one or more of the following 6 general options for evaluating heat exchangers.

1. Look for rust at furnace exhaust and vent connector.



Furnace heat exchangers: Although no heat exchanger is completely airtight, it should not leak enough to display the warning signs described here.

2. Look for flame-damaged areas near the burner flame. Look for flame impingement on the heat exchanger during firing.
3. Observe flame movement, change in chimney draft, or change in CO reading as blower is turned on and off.
4. Measure the flue-gas oxygen concentration before the blower starts and just after it has started. There should be no more than a 1% change in the oxygen concentration.
5. Examine the heat exchanger, shining a bright light on one side and looking for light traces on the other using a mirror or inspection scope to peer into tight locations.
6. Employ chemical detection techniques, following manufacturer's instructions.

Heat exchangers with large leaks should always be replaced.

2.2 Shell and Duct Testing

The testing described here will help you analyze the existing air barriers–in both the building shell and ducts–and decide whether and where air sealing is needed.

An air barrier, aligned with the insulation, forms the building's thermal boundary. The location and condition of the air barrier has a substantial effect on the insulation's effectiveness.

The energy impact of duct leakage depends on whether the ducts are located within or outside of the thermal boundary. Not all duct leaks are an energy problem.

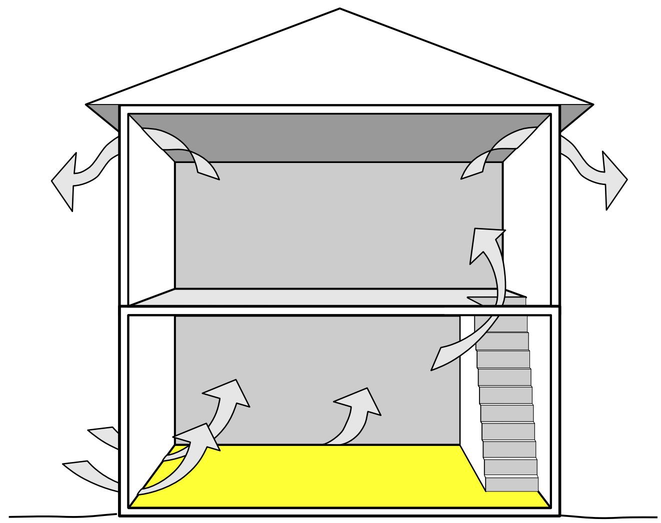
Air leakage effects

Controlling shell air leakage is the key ingredient in a successful weatherization job. The decisions you make about sealing air leaks will have a large effect on a building throughout its lifetime.

- Air leakage can significantly reduce insulation R-value.
- Air leakage can account for up to 40% of a building's heat loss.
- Air leakage moves moisture into and out of the house, and so exerts a wetting and/or drying effect.
- The location and amount of air leakage can determine whether or not a combustion appliance like a furnace or fireplace will vent its gases out the chimney as it should.

Sometimes air leakage provides ventilation for exhausting pollutants and admitting fresh air. However, air leaks can bring pollutants into the home as easily as they expel or dilute them.

Air sealing or duct sealing may affect combustion-appliance venting by changing house pressures or reducing the available supply of combustion air. After all weatherization measures have been performed, technicians must conduct worst-case draft testing and check the safety of all combustion appliances.



Air leakage through the building shell: Leakage through the shell decreases comfort and increases heating and cooling costs. In cold climates, it may deposit moisture into building cavities.

Goals of air-leakage testing

The first goal of air-leakage and pressure testing is to decide how much time and effort is required to achieve cost-effective air-leakage and duct-leakage rates, while safeguarding indoor air quality. *See section 1.1.*

The second goal of leak testing is to decide where to locate the air barrier when an intermediate zone like an attic or crawl space presents two choices of air barriers. The ceiling is usually the thermal boundary, for example, rather than the roof. However, at the foundation, the air barrier can be located at the first floor or at the foundation wall. Air leakage testing help establish the best place to locate the air barrier.

Duct leakage in the heating system is now established as one of the major treatable energy problems in homes. However, sealing every joint without testing can be a waste of time and money. Duct-leakage tests help you determine the severity and locations of duct leaks.

The reason for the number of air-leakage and duct-leakage tests is that there is so much uncertainty about air leakage and duct leakage. Testing is needed because there simply is no accurate prescriptive method for determining the severity and location of leaks. Depending on the complexity of a home, you may need to perform varying levels of testing to assess shell and duct leakage.

Cost-effective air sealing

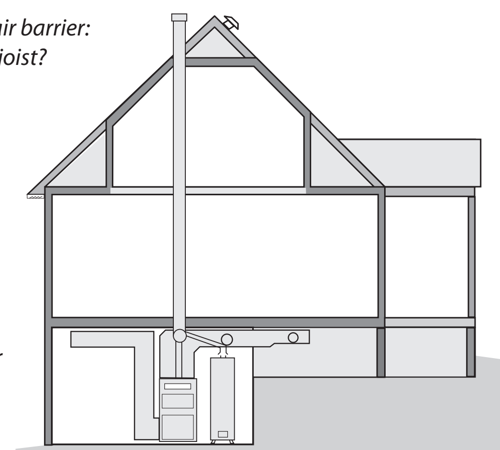
It is most cost-effective to seal the large air leaks first. Chasing small leaks isn't usually worth the effort.

- ✔ Perform shell and duct air tightness testing.
- ✔ Analyze the test results to determine if air sealing will be cost-effective.
- ✔ Locate and seal the air leaks.
- ✔ Re-test to assess the effectiveness of air sealing efforts.
- ✔ Stop air sealing when additional air sealing is not cost-effective, or when the building tightness limit is reached.

When not to air seal

Perform no air-sealing when these situations present an obvious threat to the occupants health, the installers health, the building's durability, or to the effectiveness of the air-sealing materials.

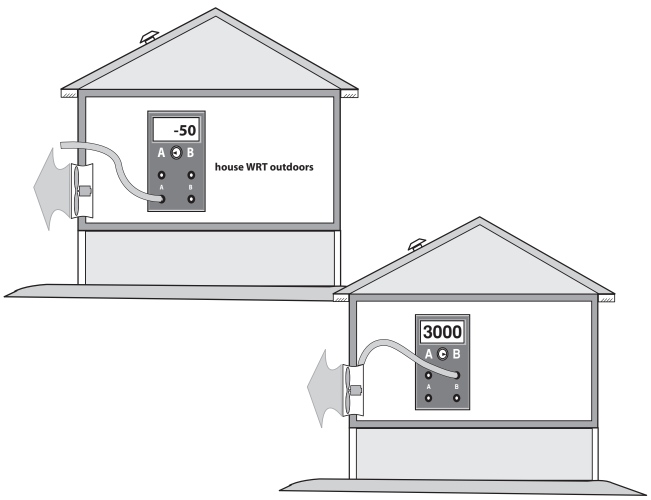
- Moisture has caused structural damage, rot, mold or mildew growth, and can't be corrected.
- Indoor air quality issues can't be resolved.
- Fire hazards jeopardize the building or the occupants' safety.
- Chimney drafts measured at combustion appliances don't meet minimum standards.
- Unvented space heaters will be used in the building.
- Measured carbon monoxide level exceeds suggested action level.
- Combustion-zone pressure exceeds -4 pascals during a worst-case test.
- The building is already at or below its Building Tightness Limit, and no mechanical ventilation is installed or planned.
- Infestations, vermin, or other sanitary issues can't be corrected.



Questions to ask during the audit: Your answers help determine the most efficient and cost-effective location for the air barrier.

2.3 Blower-door Testing

The blower door creates a 50-pascal pressure difference across the building shell and measures airflow in cubic feet per minute at 50 Pascals (CFM_{50}), in order to compare the leakiness of homes. The blower door also creates pressure differences between rooms in the house and intermediate zones like attics and crawl spaces that can give clues about the location and size of a home's air leaks. *See section 2.5.*

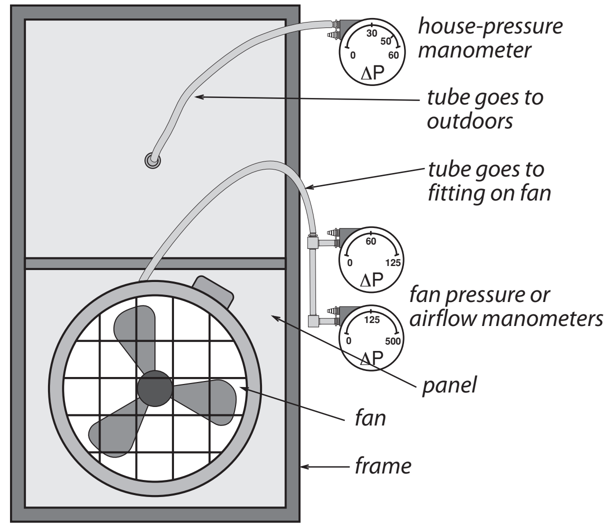


Blower door test: Air barriers are tested during a blower-door test, with the house at a pressure of 50 pascals negative with reference to outdoors. This house has 3000 CFM_{50} of air leakage. Further diagnostic tests can help determine where that leakage is coming from.

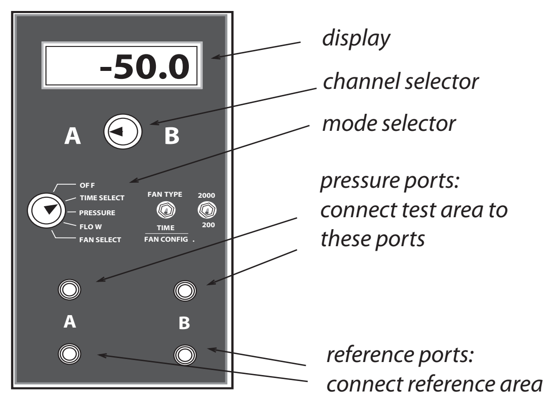
Blower-door nomenclature

Connecting the manometer's hoses correctly is essential for accurate testing. A widely accepted method for communicating correct hose connection helps avoid confusion.

The common nomenclature uses the phrase with-reference-to (WRT), to distinguish between the input zone and reference zone for a particular measurement. The outdoors is the most commonly used reference zone for blower door testing. The reference zone is considered to be the zero point on the pressure scale.



Blower door components: Include the frame, panel, fan, and manometers.



Digital manometers: Used to diagnose house and duct pressures quickly and accurately.

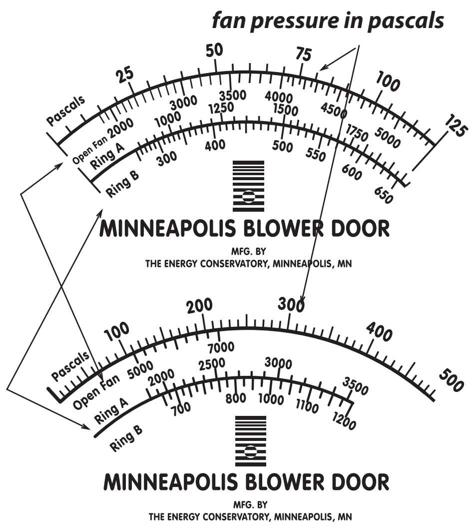
For example, *house WRT outdoors* = –50 pascals means that the house (input) is 50 pascals negative compared to the outdoors (reference or zero-point). The pressure reading in the last example is called the house-to-outdoors pressure difference.

Low-flow plates

During the blower door test, the airflow is measured through the fan. This airflow is directly proportional to the surface area of the home's air leaks. For the blower door to measure airflow accurately, the air must be flowing at an adequate speed. Tighter buildings don't have enough air leakage to create an adequate airspeed. This necessitates using one of three low-flow plates provided with the blower door to reduce the fan's opening and increase air speed through the fan to a speed at which it can be measured accurately.

When using one of these low-flow plates, you must read the correct scale on the analog gauges, shown below. When using a digital gauge, follow the manufacturer's instructions for selecting the proper fan configuration corresponding to the correct low-flow plate.

Read from either of these scales when operating the blower door with the rings removed. This orientation is called "open fan."



Read from the correct scale depending on which low-flow plate, Ring A or Ring B, is installed.

Blower door analog gauges: Blower door airflow gauges provide ranges for accurate measurement of homes with a wide variety of airtightness.

Can't reach fifty

Some homes are so leaky that the blower door isn't powerful enough to depressurize them to –50 pascals. In these cases, you must apply a factor to the airflow you measure at a lower pressure. Use these factors only when absolutely necessary because they may result in inaccurate air-leakage estimates.

Table 2.3.1: Can't-Reach-Fifty Factors

House Pressure	15	20	25	30	35	40	45
Can't Reach Fifty Factor	2.2	1.8	1.6	1.4	1.3	1.2	1.1

Courtesy of The Energy Conservatory

PREPARING FOR A BLOWER DOOR TEST

Preparing the house for a blower door test involves putting the house in its heating or cooling operating condition with all conditioned zones open to the blower door. Try to anticipate safety problems that the blower door test could cause, particularly with combustion appliances.

- ✔ Identify the location of the thermal boundary and determine which house zones are conditioned.
- ✔ Identify and repair large air leaks that could prevent the blower door from achieving adequate house pressure.
- ✔ Survey pollutants that may pollute the air during a blower door test—wood-stove or fireplace ashes for example.
- ✔ Put the house in its heating and/or cooling mode with windows, doors, and vents closed and air registers open.
- ✔ Turn off combustion appliances temporarily.
- ✔ Open interior doors so that all indoor areas inside the thermal boundary are connected to the blower door.
- ✔ Measure house volume if you plan to use ACH_{50} (air changes per hour at 50 pascals) or ACH_n (air changes per hour—natural).

Zeroing the manometers

To obtain accurate blower door measurements, you must zero the manometers. The procedure for zeroing a manometer is different for analog manometers versus digital manometers.

Analog manometer: Block the blower door's opening to prevent ambient airflow through the fan.

Make sure that the house-pressure hose is connected to outdoors and that the fan hose is disconnected. Tap each gauge face with your finger to make sure that the needle isn't stuck. Use the adjustment screw on the face of the dial to set the needle at exactly zero.

Digital manometer: Block the blower door's opening to prevent ambient airflow through the fan. Make sure that the house-pressure hose is connected to outdoors and that the fan hose is disconnected. Measure the house pressure with the blower door off. If you read a positive house pressure of a few pascals with reference to outdoors, add those pascals to 50 pascals and set the house pressure at 50+ pascals to get your accurate airflow (CFM_{50}). If you read a negative house pressure with reference to outdoors, subtract those pascals from 50 pascals, and then set the blower door to produce 50 pascals to get your accurate airflow.

Blower door test procedures

Follow this general procedure when performing a blower-door test.

1. Install blower door frame, panel, and fan in an exterior doorway with a clear path to outdoors. On windy days, try to place the fan parallel to the wind direction.
2. Follow manufacturer's instructions for fan orientation and manometer setup for either pressurization or depressurization.
3. Connect the house-pressure manometer to measure house WRT outdoors. Place the outside hose at least 5 feet to the side of the fan and against the foundation.
4. Connect the airflow manometer to measure fan WRT zone near fan inlet. The zone near the fan inlet is indoors for depressurization and outdoors for pressurization.
5. Make pretest adjustments to manometers following manufacturer's instructions. Zero manometers as described previously.
6. Ensure that children and pets are at a safe distance from the fan. Turn on the fan and increase its speed slowly until you read 50 pascals of pressure difference between indoors and outdoors.
7. Read the CFM_{50} from the airflow manometer or from the second channel of a two-channel digital manometer.
8. If the house is so leaky or large that it cannot be depressurized to –50 pascals, depressurize to highest multiple of 5 and multiply your measured airflow by the "can't reach fifty" (CRF) factors in the conversion table.
9. Record the reading.

Blower-door test follow-up

Be sure to return the house to its original condition.

- ✔ Inspect combustion appliance pilot lights to ensure that blower door testing did not extinguish them.
- ✔ Reset thermostats of heaters and water heaters that were turned down for testing.
- ✔ Remove any temporary plugs that were installed to increase house pressure.

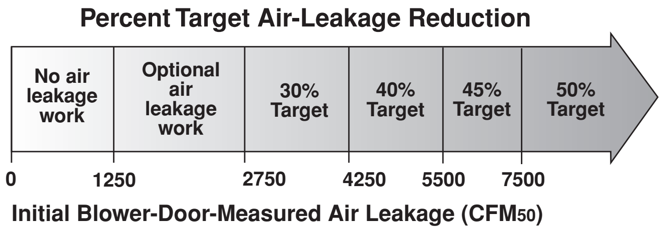
Approximate leakage area

There are several ways to convert blower-door CFM_{50} measurements into square inches of total leakage area. A simple and rough way to convert CFM_{50} into an approximate leakage area (ALA) is to divide CFM_{50} by 10. The ALA can help you visualize the size of openings you're looking for in a home or section of a home.

$$\mathbf{ALA = CFM_{50} \div 10}$$

Target air-leakage reductions

Depending on the initial CFM_{50} blower-door test reading, consider the prescribed target air-leakage reduction values specified below. These percentage reductions represent minimum values.



Air-leakage targets: These minimum air-leakage standards are considered unambitious by many.

POLLUTANT CONTROL

The control of pollutants such as moisture, radon, and volatile organic compounds is of increasing concern when homes are sealed. *See section 1.1.*

The control of pollutants at the source is always the best solution, especially so in tighter homes. Mechanical ventilation can help remove and dilute pollutants, but ventilation should not be relied upon as a sole method of pollutant control.

Technicians should survey the home for pollutants before performing air-sealing, and perform the following pollutant control measures if needed.

- Repair roof and plumbing leaks.
- Install a ground moisture barrier over any bare soil in crawl spaces or basements.
- Duct dryers and exhaust fans to the outdoors.
- Confirm that combustion appliance vent systems operate properly. Do not air seal homes with unvented space heaters.
- Move paints, cleaning solvents, and other chemicals out of the conditioned space if possible.

The home's occupants have control over the introduction and spread of many home pollutants. Always educate the residents about minimizing pollutants in the home.

2.4 BUILDING TIGHTNESS LIMITS

In most buildings, air leakage must provide sufficient outdoor air to protect human health (by diluting pollutants), and support combustion appliances (by supplying oxygen and counter-acting depressurization). The exception is buildings with continually operating mechanical ventilation that provide a supply of outdoor air where needed.

The Building Tightness Limit (BTL) establishes the minimum level beyond which buildings should not be tightened unless mechanical ventilation is installed. BTL is usually described as air leakage in CFM_{50}, since this can be measured with the blower door.

The standard most commonly used is ASHRAE 62-1989. It calls for a BTL of 0.35 air changes per hour under natural conditions (0.35 CFM_N), but *not less than* 15 cubic feet per minute under natural conditions (15 CFM_N) per occupant. Both methods are described here:

- BTL based on house volume
- BTL based on occupancy

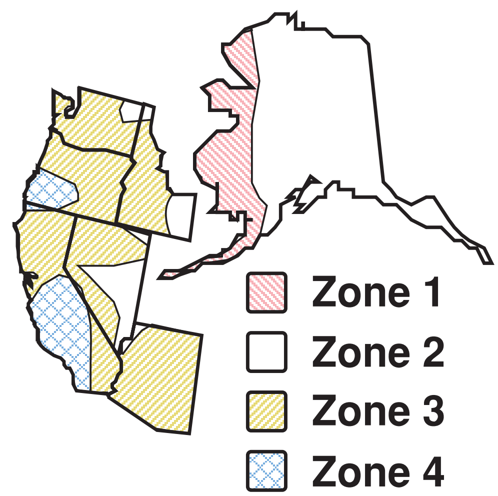
Many organizations choose to perform both calculations, then choose the most restrictive standard, which is the higher number.

Calculating n-factor

The ASHRAE standard measures leakage under normal pressure conditions. A conversion factor (n-factor) is usually used to convert leakage as measured during a blower door test (CFM_{50}) to leakage as measured under natural conditions (CFM_N), or visa versa. This n-factor accounts for average temperature in the region, the height of the home, and the typical wind at the site. Note that 80-90% of all homes have normal wind shielding.

Calculate n-factor by this method.

1. Find your climate zone on the map.
2. Match that zone number with the same zone number on the table.
3. Identify your site as well-shielded, normal, or exposed.
4. Identify the column for your building's number of stories.
5. Follow that column down to where it meets the row corresponding to your climate zone and shielding to find the n-factor.
6. Use n to convert 50-pascal airflows to natural or vice versa.
7. Find the building tightness limit (BTL), based on either house volume or occupancy.



Zone	# of stories →	1	1.5	2	3
1	Well-shielded	18.6	16.7	14.9	13.0
	Normal	15.5	14.0	12.4	10.9
	Exposed	14.0	12.6	11.2	9.8
2	Well-shielded	22.2	20.0	17.8	15.5
	Normal	18.5	16.7	14.8	13.0
	Exposed	16.7	15.0	13.3	11.7
3	Well-shielded	25.8	23.2	20.6	18.1
	Normal	21.5	19.4	17.2	15.1
	Exposed	19.4	17.4	15.5	13.5
4	Well-shielded	29.4	26.5	23.5	20.6
	Normal	24.5	22.1	19.6	17.2
	Exposed	22.1	19.8	17.6	15.4

BTL FROM HOUSE VOLUME

This formula requires a measurement of the home's volume, in cubic feet, and determination of the n-factor for the site.

Formula: BTL from house volume:

$$\text{BTL (CFM}_{50}) = \frac{0.35 \times \text{Volume} \times n}{60}$$

Example:

A one-story home
30' x 42' with 8' ceilings,
Located in Zone 3 with normal wind shielding
(n-factor = 21.5)

***Formula for volume*:**

Length x Width x Height
of all rooms within the living space
(30' x 42' x 8' = 10080 cubic feet)

Example calculation:

$$\text{BTL} = \frac{0.35 \text{ X } 10080 \text{ X } 21.5}{60} = 1264 \text{ CFM}_{50}$$

BTL FROM OCCUPANCY

The BTL as calculated from occupancy requires that air leakage provide a minimum of 15 CFM of fresh air for each person to maintain acceptable indoor air quality.

Determine the number of occupants by counting the bedrooms, and adding one. But always assume a minimum of five occupants.

Formula: BTL from occupancy:

$$\text{BTL (CFM}_{50}) = 15 \times (\text{\# of occupants}) \times n$$

Example:

A home with 4 bedrooms
(You should assume 5 occupants)
Located in Zone 3 with normal wind shielding
(n-factor 21.5)

Example calculation:

$$\text{BTL} = 15 \times 5 \times 21.5 = 1612 \text{ CFM}_{50}$$

2.5 Zone Pressure Tests

Leaks in air barriers cause energy and moisture problems in many homes. Air-barrier leak-testing avoids unnecessary visual inspection and air sealing in hard-to-reach areas.

Advanced pressure tests measure pressure differences between zones in order to estimate air leakage between zones. Use these tests to make decisions about where to direct your air-sealing efforts.

- Evaluate the airtightness of portions of a building's air barrier—especially floors and ceilings.
- Decide which of two possible air barriers to air seal—for example, the floor versus foundation walls.
- Estimate the air leakage in CFM_{50} through a particular air barrier, for the purpose of estimating the effort and cost necessary to seal the leaks.
- Determine whether building cavities like floor cavities, porch roofs, and overhangs are conduits for air leakage.
- Determine whether building cavities, intermediate zones, and ducts are connected by air leaks.

Air-barrier tests provide a range of information from simple clues about which parts of a building are leakiest, to specific estimates of the airflow and hole size through a particular air barrier.

Table 2.5.1: Building components and their air permeance

Good air barriers (<2 CFM_{50} per 100 ft.^{2})	Fair air barriers (2–10 CFM_{50} per 100 ft.^{2})	Poor air barriers (10–1000 CFM_{50} per 100 ft.^{2})
5/8″ oriented strand board	15# perforated felt	5/8″ tongue-and-groove wood sheeting
1/2″ drywall	concrete block	6" fiberglass batt
4-mil air barrier paper	rubble masonry	1.5" wet-spray cellulose
Asphalt shingles and perforated felt over 1/2″ plywood	7/16″ asphalt-coated fiberboard	wood siding over plank sheathing
1/8″ tempered hardboard	1" expanded polystyrene	wood shingles over plank sheathing
painted uncracked lath and plaster	brick veneer	blown fibrous insulation

Measurements taken at 50 pascals pressure.
Based on information from: "Air Permeance of Building Materials" by Canada Mortgage Housing Corporation, and estimates of comparable assemblies by the author.

Primary versus secondary air barriers

The air barrier should be a material that is continuous, sealed at seams, and relatively impermeable to airflow. Where there are two possible air barriers, the most airtight air barrier is the primary air barrier and the least airtight is the secondary air barrier.

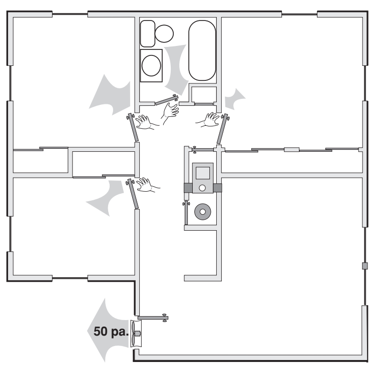
The primary air barrier should be adjacent to the insulation to ensure the insulation's effectiveness. Testing is important to verify that insulation and primary air barrier are together. Sometimes we're surprised during testing to find that our assumed primary air barrier is actually secondary, and the secondary air barrier is actually primary.

Intermediate zones are unconditioned spaces that are sheltered within the exterior shell of the house. Intermediate zones can either be included inside the home's primary air barrier or outside it. Intermediate zones include: unheated basements, crawl spaces, attics, enclosed porches, and attached garages.

Intermediate zones have two potential air barriers: one between the zone and house and one between the zone and outdoors. For example, an attic or roof space has two air barriers: the ceiling and roof. It is useful to know where the best air barrier is located.

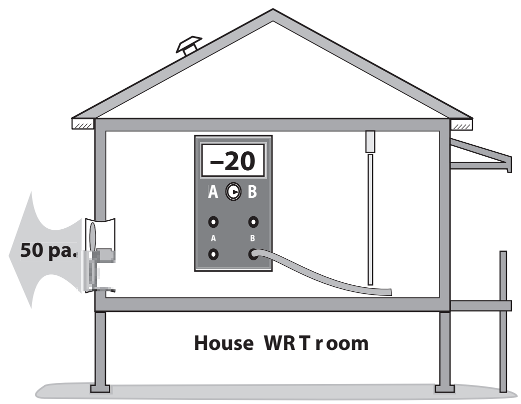
SIMPLE PRESSURE TESTS

You can find valuable information about the relative leakiness of rooms or sections of the home during a blower-door test. Listed below are five simple methods



Interior door test: Feeling airflow with your hand at the crack of an interior door gives a rough indication of the air leakage coming from the outdoors through that room.

1. *Feeling zone air leakage:* While the home is depressurized, close an interior door partially so that there is a one-inch gap between the door and door jamb. Feel the airflow along the length of that crack, and compare that airflow intensity with airflow from other rooms, using the same technique.
2. *Observing the ceiling/attic floor:* Pressurize the home and observe the top-floor ceiling from the attic with a good flashlight. Air leaks will show in movement of loose-fill insulation, blowing dust, moving cobwebs, etc. You can also use a small piece of tissue paper to disclose air movement.
3. *Observing smoke movement:* Pressurize the home and observe the movement of smoke through the house and out of its air leaks.
4. *Room pressure difference:* Check the pressure difference between a closed room or zone and the main body of a home. Larger pressure differences indicate larger potential air leakage within the closed room or else a tight air barrier between the room and main body. A small pressure difference means little leakage to the outdoors through the room or a leaky air barrier between the house and room.



Bedroom test: This bedroom pressure difference may be caused by its leaky exterior walls or tight interior walls, separating it from the main body of the home. This test can determine whether or not a confined combustion zone is connected to other rooms.

5. *Room airflow difference:* Measure the house CFM_{50} with all interior doors open. Close the door to a single room, and note the difference in the CFM_{50} reading. The difference is the approximate leakage through that room.

Tests 1, 2, and 3present good client education opportunities. Feeling airflow or observing smoke are simple observations, but have helped identify many air leaks that could otherwise have remained hidden.

When airflow within the home is restricted by closing a door, as in tests 4 and 5, it may take alternative indoor paths that render these tests somewhat inaccurate. Only practice and experience can guide your decisions about the applicability and usefulness of these general indicators.

ROOM PRESSURE TESTS

A manometer pressure gauge, used for blower-door testing, also can measure pressures between the house and its intermediate zones during blower-door tests.

The blower door, when used to create a house-to-outdoors pressure of –50 pascals, also creates house-to-zone pressures of between 0 and –50 pascals in the home's intermediate zones. The amount of depressurization depends on the relative leakiness of the zone's two air barriers.

For example, in an attic with a fairly airtight ceiling and a well-ventilated roof, the attic will indicate that it is mostly outdoors by having a house-to-zone pressure of –45 to –50 pascals. The leakier the ceiling and the tighter the roof, the smaller the negative house-to-zone pressure will be. This holds true for other intermediate zones like crawl spaces, attached garages, and unheated basements.

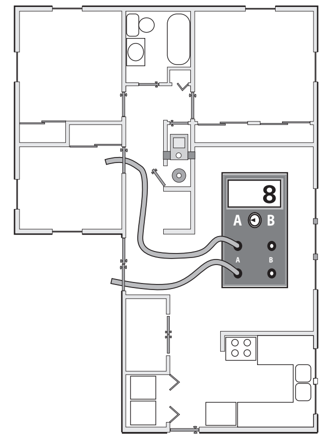
Room pressure imbalance

Follow these steps to check for and remedy imbalances in room pressures.

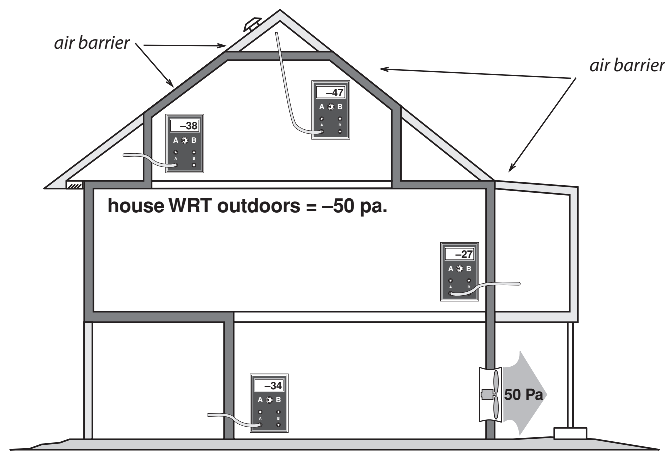
1. Leave the house in winter conditions, and leave the air handler running.
2. Close interior doors.
3. Place hose from input tap on the manometer under one of the closed interior doors. Leave reference tap connected to outdoors.
4. Read and record this pressure measurement for each room. This pressure's magnitude indicates the degree to which the air-handler's airflow is unbalanced between supply and return.

If the pressure difference is more than ± 4.0 pascals with the air handler operating, pressure relief is necessary. To estimate the amount of pressure relief, slowly open door until pressure difference drops to between +4.0 pascals and –4.0 pascals. Estimate opened area of the door. This is the area required to provide pressure relief. Pressure relief may include undercutting the door, installing transfer grilles, or adding jumper or dedicated return ducts.

Blocked return path: With interior doors closed, the large positive pressure in the bedroom is caused by the lack of a air return register in the bedroom. The airflow in this forced-air system is unbalanced, creating this pressure, and forcing room air through the room's air leaks.



Zone leak-testing methodology

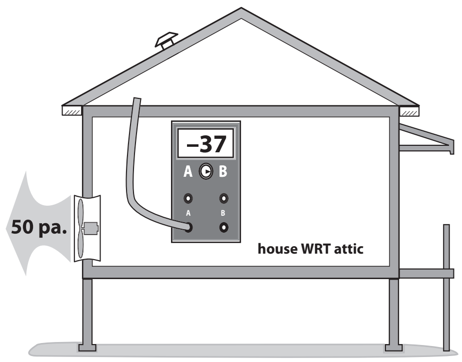


Pressure-testing building zones: Measuring the pressure difference across the assumed thermal boundary tells you whether the air barrier and insulation are aligned. If the manometer reads close to –50 pascals, they are aligned, assuming the tested zones are well-connected to outdoors.

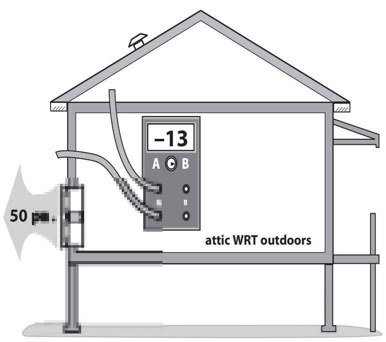
Depressurize house to –50 pascals with a blower door.

1. Find an existing hole, or drill a hole through the floor, wall, or ceiling between the conditioned space and the intermediate zone.
2. Connect the reference port (digital manometer) or the low-pressure port (analog manometer) to a hose connected into the zone.
3. Leave the input port (digital manometer) or the high-pressure port (analog manometer) open to the indoors.

4. Read the negative pressure given by the manometer. This is the house-to-zone pressure, which will be –50 pascals if the air barrier between house and zone is airtight and the zone is open to outdoors.
5. If the reading is significantly less negative than –45 pascals, find the air barrier's largest leaks and seal them.
6. Repeat steps 1 through 5, performing more air-sealing as necessary, until the pressure is as close to –50 pascals as possible.



House-to-attic pressure: This commonly used measurement is convenient because it requires only one hose.



Attic-to-outdoors pressure: This measurement confirms the first because the two add up to –50 pascals.

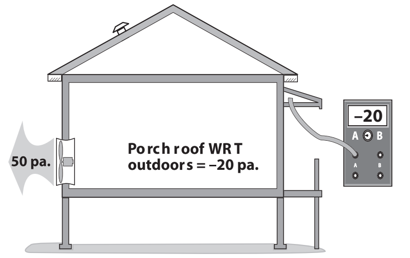
Leak-testing building cavities

Building cavities such as wall cavities, floor cavities between stories, and dropped soffits in kitchens and bathrooms can also be tested as described above to determine their connection to the outdoors as shown here.

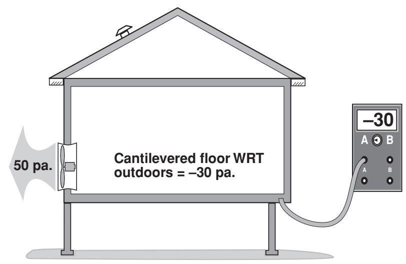
Testing zone connectedness

Sometimes it is useful to determine whether two zones are connected by an air passage like a large bypass. Measuring the house-to-zone pressure during a blower door test before and then after opening the other zone to the outdoors can establish whether the two zones are connected. You can also open an interior door to one of the zones and check for pressure changes in the other.

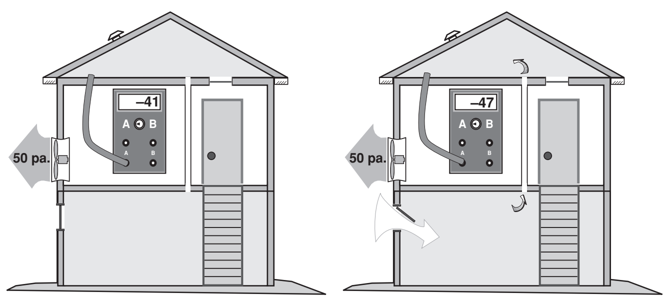
These examples assume that the manometer is outdoors with the reference port open to outdoors



Porch roof test: If the porch roof were outdoors, the manometer would read near 0 pascals. We hope that the porch roof is outdoors because it is outside the insulation. We find, however, that it is partially indoors, indicating that it may harbor significant air leaks through the thermal boundary.



Cantilevered floor test: We hope to find the cantilevered floor to be indoors. A reading of –50 pascals would indicate that it is completely indoors. A reading less negative than –50 pascals is measured here, indicating that the floor cavity is partially connected to outdoors.



Zone connectedness: The attic measures closer to outdoors after the basement window is opened, indicating that the attic and basement are connected by a large bypass.

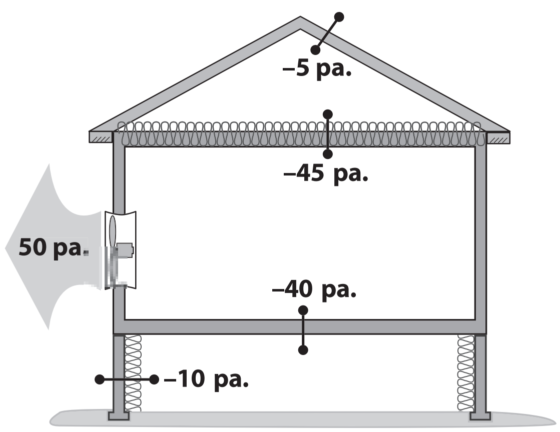
LOCATING THE THERMAL BOUNDARY

Zone pressures are one of several factors used to determine where the thermal boundary should be. Where to air-seal and where to insulate are necessary retrofit decisions. When there are two choices of where to insulate and air-seal, zone pressures along with other considerations help you decide.

For zone leak-testing, the house-to-zone pressure is often used to determine which of two air barriers is tighter.

- Readings of negative 25-to-50 pascals house-to-attic pressure mean that the ceiling is tighter than the roof. If the roof is quite airtight, achieving a 50-pascal house-to-attic pressure difference may be difficult. However if the roof is well-ventilated, achieving a near-50-pascal difference should be possible.
- Readings of negative 0-to-25 pascals house-to-attic pressure mean that the roof is tighter than the ceiling. If the roof is well-ventilated, the ceiling has even more leak area than the roof's vent area.
- Readings around –25 pascals house-to-attic pressure indicate that the roof and ceiling are equally airtight or leaky.

Pressure readings more negative than –45 pascals indicate that the primary air barrier is adequately airtight. Less negative pressure readings indicate that air leaks should be located and sealed.



Pressure measurements and air-barrier location: The air barrier and insulation are aligned at the ceiling. The crawl-space pressure measurements show that the floor is the air barrier and the insulation is misaligned—installed at the foundation wall. We could decide to close the crawl space vents and air-seal the crawl space. Then the insulation would be aligned with the air barrier.

Floor vs. crawl space

The floor shown here is tighter than the crawl-space foundation walls. If the crawl-space foundation walls are insulated, holes and vents in the foundation wall should be sealed until the pressure difference between the crawl space and outside is as negative you can make it—ideally more negative than –45 pascals. A leaky foundation wall renders its insulation nearly worthless.

If the floor above the crawl space were insulated instead of the foundation walls in the above example, the air barrier and the insulation would be aligned.

If a floor is already insulated, it makes sense to establish the air barrier there. If the foundation wall is more airtight than the floor, that would be one reason to insulate the foundation wall.

Attic boundary

Generally, the thermal boundary (air barrier and insulation) should be between the conditioned space and attic. An exception would be insulating the roof to enclose an attic air handler and its ducts within the thermal boundary.

Garage boundary

The air barrier should always be between the conditioned space and a tuck-under or attached garage, to separate the living spaces from this unconditioned and often polluted zone.

Duct location

The location of ducts either within or outside the thermal boundary is an important factor in determining the cost-effectiveness of duct sealing and insulation. Including the heating ducts within the thermal boundary is preferred because it reduces energy waste from duct leakage.

Add-a-hole zone leakage measurement

If you are still unsure of the location and severity of air leaks after the simpler diagnostic tests, you can use this add-a-hole procedure to estimate the actual airflow between the house and attic. Use your programmable calculator to perform the calculations. If you don't have a calculator, use the tables provided here.

Based on the original house-to-attic pressure you measure, *Table 2.5.2* allows you to choose one of three pressure drops (5, 10, and 15 pascals) that you create by opening a hole by way of an attic hatch or other opening between the house and attic. You estimate the area of the opening required to achieve that pressure drop. *Table 2.5.2* then provides a multiplier to convert square inches of opening to CFM_{50}. After determining this CFM_{50} leakage figure, you can determine the percentage of the home's air leakage coming through the attic.

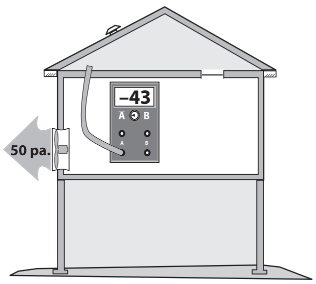
Follow this procedure.

1. Establish hoses into attic (or other zone) for measuring house WRT attic.
2. Depressurize house to –50 pascals.
3. Record the house's CFM_{50}.
4. Measure and record the house-to-attic pressure (or other zone pressure). Locate that house-to-zone pressure in the H/Z column of *Table 2.5.2.* For each initial pressure there are values for CFM_{50} per square inch of opening for three specific pressure drops, 5, 10, and 15 pascals.
5. Reduce the pressure you found in Step 4 by 5, 10, or 15 pascals by opening the attic hatch while increasing the blower door's speed to maintain –50 pascals house-to-outdoors pressure difference. When you reach your target house-to-attic pressure, make sure the house-to-outdoor pressure is still –50 pascals.
6. Estimate the area of the opening you made in Step 5. Multiply this opening's estimated area in square inches times the factor in *Table 2.5.2* to find the CFM_{50} leaking between house and attic.

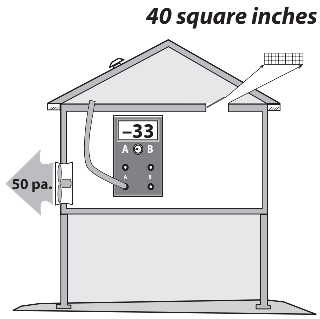
Table 2.5.2: Add-a-hole CFM_{50} per square inch of hole

Measured Pressure in Pascals		**Pressure Drop**			**Measured Pressure in Pascals**		**Pressure Drop**		
H/Z[a]	**Z/O[b]**	**5 Pa**	**10 Pa**	**15 Pa**	**H/Z[a]**	**Z/O[b]**	**5 Pa**	**10 Pa**	**15 Pa**
49	1	3	1.7	1.1	35	15	19	9	6.8
48	2	5	2.8	1.9	34	16	19	9	6.9
47	3	7	4	2.5	33	17	19	9	7.0
46	4	9	5	3.1	32	18	19	9	7.1
45	5	11	6	3.6	31	19	20	9	7.1
44	6	12	6	4.1	30	20	20	9	7.1
43	7	13	7	4.5	29	21	20	8	7.0
42	8	14	7	4.9	28	22	19	8	7.0
41	9	15	7	5.3	27	23	19	8	6.8
40	10	16	8	5.6	26	24	18	8	6.7
39	11	17	8	5.9	25	25	18	8	6.5
38	12	17	8	6.2	20	30	15	6	--
37	13	18	8	6.5	15	35	10	3	--
36	14	18	8	6.6	10	40	5	--	--
Courtesy of Michael Blasnik									

a. House-to-Zone pressure difference
b. Zone-to-Outdoors pressure difference



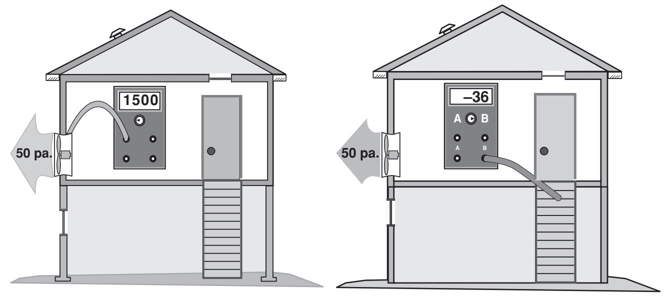
Add-a-hole test: The first house-to-attic pressure is –43 pascals. If we drop the pressure by 10 pascals, every square inch of opening will represent 7 CFM_{50} of leakage between house and attic. *See Table 2.5.2.*



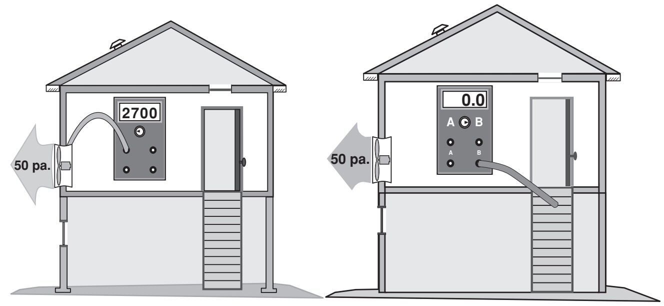
Add-a-hole test 2: Opening a hole of approximately 40 square inches drops the second house-to-zone pressure by 10 pascals.

Opening area (sq.in.) x factor (CFM_{50}/sq.in.) = CFM_{50}

40 sq.in. x 7 CFM_{50}/sq.in. = 280 CFM_{50}



Open-a-door test: Start with a CFM_{50} reading and a pressure difference between house and the basement zone.



Open-a-door test 2: Now open the door, and read the new CFM_{50}, while making sure that there is no pressure difference across the door.

CFM_{50} DIFFERENCE X LEAKAGE RATIO =

CFM_{50} (HOUSE/ZONE OR ZONE/EXTERIOR)

1200 CFM_{50} X .96 = 1150 CFM_{50}

Calculation for house-to-zone leakage

1200 CFM_{50} X 1.78 = 2140 CFM_{50}

Calculation for zone-to-outdoors leakage

OPEN-A-DOOR ZONE-LEAKAGE MEASUREMENT

The open-a-door method is a another way of determining how much leakage in CFM_{50} travels through an intermediate zone like a walk-up attic, basement, or attached garage. This method requires a door between the house and the intermediate zone. Use your programmable calculator to perform the calculations. If you don't have a calculator, use the tables provided here.

1. Perform a blower door test and measure CFM_{50} with the door between the house and intermediate zone closed.
2. During the test, measure the pressure difference between the house and zone.
3. Open the door between house and zone and measure CFM_{50} again. Also measure the pressure difference between the house and zone. It should now be 0 pascals.
4. Find the exterior leakage factor from *Table 2.5.3*, and multiply the CFM_{50} difference between door-open and door-closed blower door tests by this factor.

Table 2.5.3: Open-a-door CFM_{50} leakage (Per CFM_{50} change upon opening)

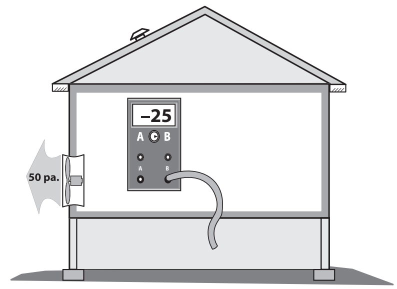
House Pressures		Leakage Ratios		House Pressures		Leakage Ratios	
H/Z	Z/O	Int Lk	Ext Lk	H/Z	Z/O	Int Lk	Ext Lk
48	2	.14	1.14	27	23	2.28	2.53
47	3	.19	1.19	26	24	2.5	2.64
46	4	.25	1.24	25	25	2.77	2.76
45	5	.31	1.29	24	26	3.05	2.89
44	6	.37	1.34	23	27	3.41	3.04
43	7	.43	1.39	22	28	3.73	3.19
42	8	.49	1.44	21	29	4.16	3.36
41	9	.56	1.49	20	30	4.61	3.54
40	10	.63	1.54	19	31	5.2	3.76
39	11	.70	1.6	18	32	5.78	3.98
38	12	.78	1.66	17	33	6.58	4.24
37	13	.87	1.72	16	34	7.38	4.52
36	14	.96	1.78	15	35	8.5	4.87
35	15	1.06	1.85	14	36	9.63	5.21
34	16	1.17	1.91	13	37	11.3	5.68
33	17	1.3	1.98	12	38	12.9	6.14
32	18	1.42	2.06	11	39	15.6	6.79
31	19	1.54	2.12	10	40	18.3	7.43
30	20	1.71	2.23	9	41	22.9	8.4
29	21	1.99	2.31	8	42	27.5	9.37
28	22	2.07	2.42	Courtesy of Michael Blasnik			

Decisions about basement and crawl spaces

The importance of creating an effective air barrier at the foundation walls or floor depends on how much of the home's air leakage is coming through the foundation or floor.

The auditor or technician may choose either the first floor or the foundation wall as the air barrier. If installing insulation in that building component is also a weatherization priority, the insulation is installed in either the floor or the foundation wall, depending on which was chosen as the air barrier. Most basements and crawl spaces in existing homes are uninsulated.

The results of air-barrier tests are only one deciding factor in selecting the thermal boundary's location. Moisture problems, duct and furnace location, and the necessity of crawl-space venting are other important considerations.



House-to-crawl-space pressure: Many homes with crawl spaces have an ambiguous thermal boundary at the foundation. Is the air barrier at the floor or foundation wall? Answer: in this case, each forms an equal part of the air barrier.

Basement insulation may not be a very practical weatherization option because of moisture concerns, cost, or the need to drywall and tape any newly insulated interior surfaces. Crawl-space insulation poses fewer problems and is often undertaken using foam sheeting, wet-spray cellulose, spray two-part foam, or even foil-faced (FSK) fiberglass.

The tables presented here summarize the decision factors for choosing between the floor and the foundation wall as the air barrier. You may also encounter situations that aren't addressed here.

When a home has a basement and crawl space connected together, both *Table 2.5.4* and *Table 2.5.5* are relevant to the decision-making process of selecting the air barrier and site for insulation, if insulation is found to be cost-effective. A basement may even be divided from its adjoining crawl space to allow the basement to be within the air barrier and the crawl space to be outside the air barrier.

Table 2.5.4: Crawl space: Where is the air barrier?

Factors favoring foundation wall	Factors favoring floor
Ground moisture barrier and good perimeter drainage present or planned	Damp crawl space with no improvement offered by weatherization
Foundation walls test tighter than floor	Floor air-sealing and insulation are reasonable options, considering access and obstacles
Vents can be closed off	Floor tests tighter than foundation walls
Furnace and ducts located in crawl space	No furnace or ducts present
Concrete or concrete block walls are easily insulated	Building code or code official forbids closing vents
Floor air-sealing and insulation would be more difficult than sealing and insulating the foundation	Ducts or water pipes located in crawl space
	Rubble masonry foundation wall
Foundation wall is insulated	Floor is already insulated

Table 2.5.5: Unoccupied basement: Where is the air barrier?

Favors foundation wall	Favors floor
Ground drainage and no existing moisture problems	Damp basement with no solution during weatherization
Interior stairway between house and basement	Floor air-sealing and insulation is a reasonable option, considering access and obstacles
Ducts and furnace in basement	No furnace or ducts present
Foundation walls test tighter than the floor	Floor tests tighter than foundation walls
Basement may be occupied some day	Exterior entrance and stairway only
Laundry in basement	Rubble masonry foundation walls
Floor air-sealing and insulation would be very difficult	Dirt floor or deteriorating concrete floor
Concrete floor	Badly cracked foundation walls

2.6 BLOWER DOOR DUCT TESTING

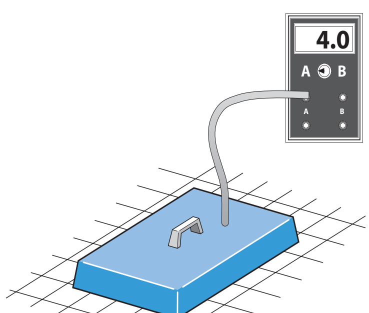
The blower door can be used for duct-airtightness testing at the same time that it is testing house airtightness. The goal of the tests explained below is to roughly estimate duct leakage so that a decision can be made about the level of duct sealing necessary.

Leaks from ducts that are located within the home's thermal boundary don't tend to incur large energy losses. They can, however, cause pressure imbalances within the home if the leaks are large. Return leaks near combustion appliances can also alter chimney draft and result in backdrafting. Worst-case draft testing is always required after duct sealing to assess the impact of this type of leakage.

PRESSURE-PAN TESTING

Pressure-pan tests can help identify leaky or disconnected ducts. With the house depressurized by the blower door to –25 or –50 pascals with reference to outdoors, pressure-pan readings are taken at each supply and return register.

Pressure-pan testing is reliable for mobile homes and small site-built homes where the ducts are outside the air barrier. Pressure pan tests do not accurately disclose duct leakage into the conditioned space.



A pressure pan: Blocks a single register and measures the air pressure behind it, during a blower door test. The magnitude of that pressure is an indicator of duct leakage.

Basements are often included in the conditioned living space of a home. In these homes, pressure-pan testing isn't necessary, although air-sealing the return ducts may be needed to protect against depressurization. But if the basement is accessed from the outside and rarely used, the basement may be considered outside the conditioned living space. In this case, a window or door between the basement and outdoors should be opened, and any door or hatch between conditioned spaces and basement should be closed during pressure-pan testing.

Follow this procedure to perform a pressure pan test.

1. Install blower door and set-up house for winter conditions. Open all interior doors.
2. If the basement is conditioned living space, open the door between basement and upstairs living spaces. If the basement is considered outside the conditioned living space, close the door between basement and upstairs living spaces and open a basement window.
3. Turn furnace off. Remove furnace filter, and tape filter slot if one exists. Ensure that all grilles, registers, and dampers are fully open.
4. Temporarily seal any outside fresh-air intakes to the duct system. Seal supply registers in zones that are not intended to be heated—an uninhabited basement or crawl space, for example.
5. Open attics, crawl spaces, and garages as much as possible to the outside so they don't create a secondary air barrier.
6. Connect a hose between pressure pan and the input tap on the digital manometer. Leave the reference tap open.
7. With the blower door at –25 pascals, place the pressure pan completely over a grille or register to form a tight seal. Record the reading, which should be a positive pressure.
8. If a grille is too large or a supply register is difficult to access (under a kitchen cabinet, for example), seal the grille or register with masking tape. Insert a pressure probe

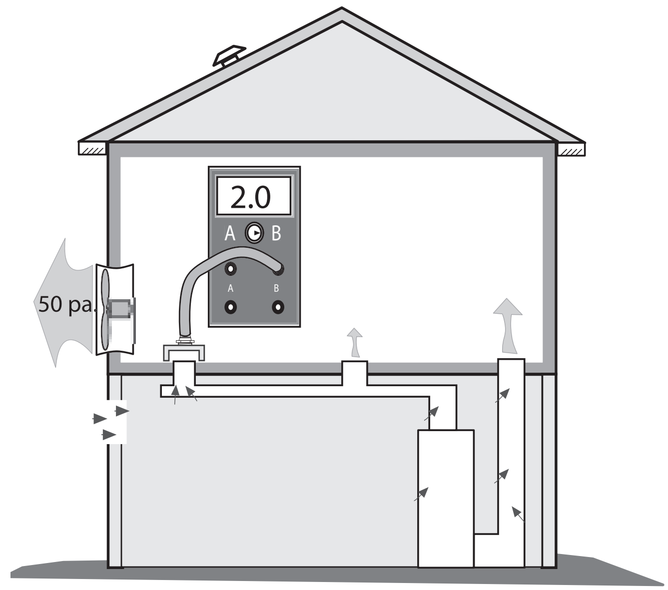
through the masking tape and record reading.

9. Repeat this test for each register and grille in a systematic fashion.

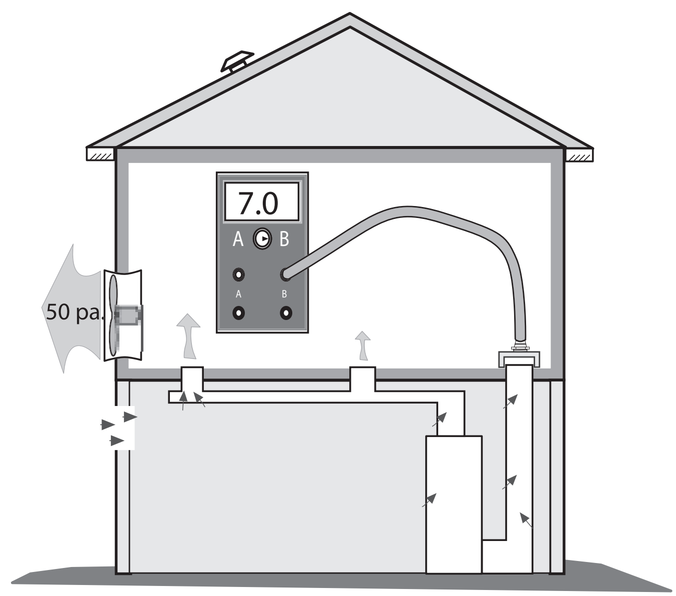
Pressure-pan duct standards

If the ducts have no leakage to the outside, no pressure difference (0 pascals) will be measured during a pressure-pan test. The higher the measured pressure-pan reading, the more connected the duct is to the outdoors. Readings greater than 1.0 pascal require investigation and sealing of leaks causing the reading.

Pay particular attention to registers connected to ducts that are located in areas outside the conditioned living space. These spaces include attics, crawl spaces, garages, and unoccupied basements as described previously. Also test return registers attached to stud cavities or panned joists used as return ducts. Leaky ducts located outside the conditioned living space may show pressure-pan readings of up to 25-to-50 pascals if they have large leaks.



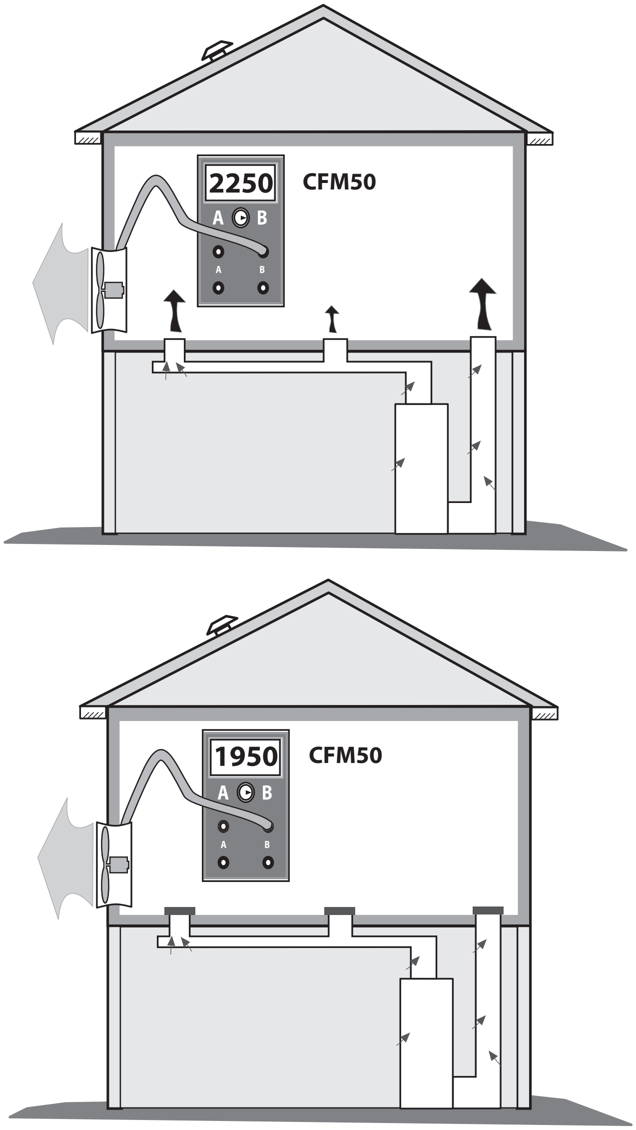
Pressure-pan test: A pressure-pan reading of 2 pascals indicates moderate duct air leakage.



Problem register: A pressure reading of 7 pascals indicates major air leakage near the tested register.

BLOWER-DOOR SUBTRACTION

This procedure provides additional diagnostic information about ducts. The blower-door subtraction method employs two separate blower-door tests: one test with registers open, and a subsequent test with registers blocked. The test assumes that the reduced blower-door reading, after the registers are blocked, is due to the elimination of duct leakage from outdoors.



Blower door subtraction: This test involves two blower door tests: one with the registers open and another with the registers taped closed. The difference between the two CFM_{50} readings, adjusted by a correction factor, is a rough estimate of duct leakage.

For best accuracy, the intermediate zone containing the ducts should be well-connected to the outdoors. If the house-to-duct pressure is –45 pascals or more, with the registers sealed, the test will be relatively accurate. If the house-to-duct pressure is a smaller negative number, this test will significantly underestimate duct leakage. Correction factors listed here make the test more accurate when the *house-to-duct* pressure is less negative than –45 pascals.

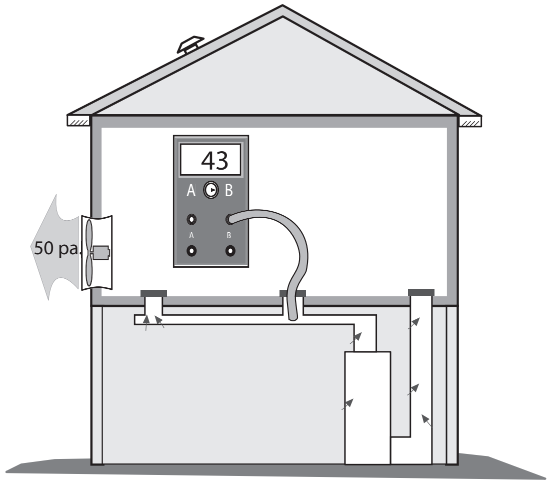
1. Take a standard blower door airflow reading (CFM_{50}) for house air leakage: *house WRT outdoors* = –50 pascals.
2. Tape over all supply and return registers and take another CFM_{50} reading.
3. Subtract the reading obtained in Step 2 from the reading in Step 1 to arrive at an estimate of duct leakage to the outdoors.
4. Measure the duct-to-house pressure through a hole in the tape at a central register or at a hole in a supply or return plenum.
5. Find the correction factor corresponding to the duct-to-house pressure measured in Step 4.
6. Multiply the correction factor times the duct-leakage estimate from Step 3.

Blower-door subtraction standards

This test gives a very approximate duct-leakage measurement, which is not accurate for small-to-moderate duct leakage.

The blower door measures large airflows, then subtracts them to get a much smaller figure for duct leakage. Small percentage errors between the two readings, due to wind or other variables, produce large errors in estimated duct leakage. The smaller the duct leakage, the greater the error. Duct leakage of 200-to-500 CFM_{50} is common in existing duct systems needing repair.

Setting realistic goals for air sealing depends on the skill level of the technicians. The best technicians may be able to reduce CFM_{50} duct leakage to around 2-to-3 percent of conditioned-floor area. Less experienced technicians may be satisfied with a blower-door subtraction at CFM_{50} of 10 percent of conditioned-floor area.



Correction factor for blower door subtraction: The pressure inside the sealed ducts serves as a correction factor to the CFM_{50} airflow difference. Match the duct pressure with the correction factors shown here. Multiply this factor times your gross leakage measurement to estimate the net duct leakage to the outdoors.

House-WRT-Duct Pressure	Subtraction Correction Factor	House-WRT-Duct Pressure	Subtraction Correction Factor
50	1.00	30	2.23
49	1.09	29	2.32
48	1.14	28	2.42
47	1.19	27	2.52
46	1.24	26	2.64
45	1.29	25	2.76
44	1.34	24	2.89
43	1.39	23	3.03
42	1.44	22	3.18
41	1.49	21	3.35
40	1.54	20	3.54
39	1.60	19	3.74
38	1.65	18	3.97
37	1.71	17	4.23
36	1.78	16	4.51
35	1.84	15	4.83
34	1.91	14	5.20
33	1.98	13	5.63
32	2.06	12	6.12
31	2.14	11	6.71

BDS CFM_{50} = CFM_{50} DIFFERENCE X CORRECTION FACT

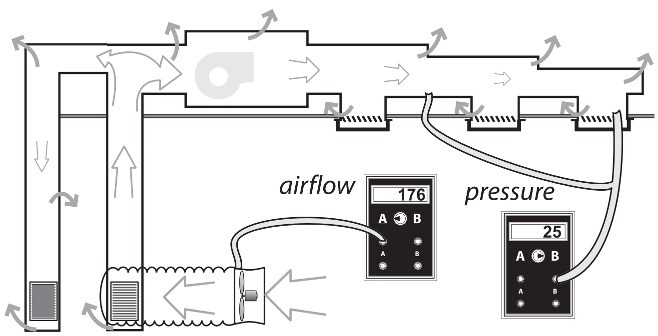
From the example: above and the correction factor shown above, the calculation would go as follows.

BDS CFM_{50} = 300 CFM_{50} X 1.39 = 417 CFM_{50}

2.7 DUCT-BLOWER LEAK-TESTING

The most accurate way to measure duct air leakage, is to pressurize the ducts using a duct blower. The duct blower is the most accurate common testing device for duct air leakage. It consists of a fan, a digital manometer or set of analog manometers, and a set of reducer plates for measuring different leakage levels.

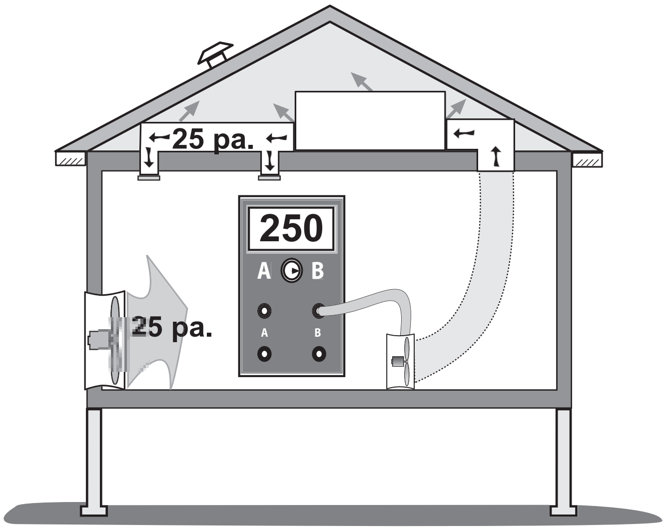
The total duct leakage test measures leakage to both indoors and outdoors. The house and intermediate zones should be open to the outdoors by way of windows, doors, or vents. Opening the intermediate zones to outdoors insures that the duct blower is measuring only the ducts' airtightness—not the airtightness of ducts combined with other air barriers like roofs, foundation walls, or garages.



Total duct air leakage measured by the duct blower: All registers are sealed except the one connecting the duct blower to the system. Pressurize the ducts to 25 pascals and measure airflow.

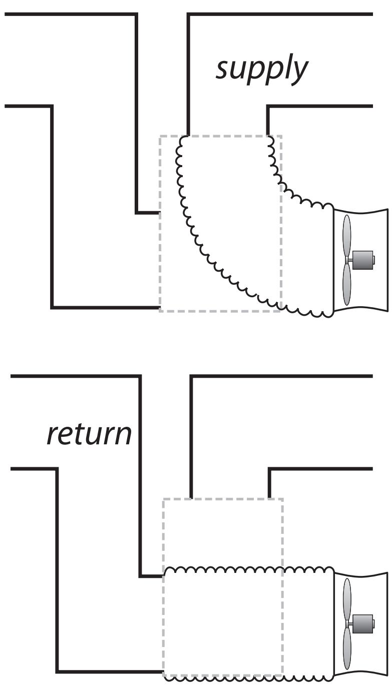
Follow these steps when performing a duct airtightness test.

1. Install the duct blower in the air handler or to a large return register, either using its connector duct or simply attaching the duct blower itself to the air handler or return register with cardboard and tape.
2. Remove the air filter(s) from the duct system.
3. Seal all supply and return registers with masking tape or other non-destructive sealant.
4. Open the house, basement or crawl space, containing ducts, to outdoors.
5. Drill a $^1/_4$ or $^5/_{16}$-inch hole into a supply duct a short distance away from the air handler and insert a manometer hose. Connect a manometer to this hose to measure *duct WRT outdoors*. (Indoors, outdoors, and intermediate zones should ideally be opened to each other in this test).
6. Connect an airflow manometer to measure *fan WRT the area near the fan*. Check manometer(s) for proper settings. Dial-and-needle manometers may need warm-up and calibration. Digital manometers require your choosing the correct mode, range, and fan-type settings.
7. Turn on the duct blower and pressurize the ducts to 25 pascals.
8. Record duct-blower airflow.
9. While the ducts are pressurized, start at the air handler and move outward feeling for leaks in the air handler, main ducts, and branches.
10. After testing and associated air-sealing are complete, restore filter(s), remove seals from registers, and check air handler.



Measuring duct leakage to outdoors: Using a blower door to pressurize the house with a duct blower to pressurize the ducts measures leakage to the outdoors—a smaller number and a bette predictor of energy savings. This test is the preferred for evaluatin duct leakage for specialists in both shell air leakage and duct air leakage whenever a blower door is available.

Supply and return ducts can also be tested separately, either before the air handler is installed in a new home or when an air handler is removed during replacement.



Testing ducts before air-handler installation: If the ducts are installed prior to the air handler, as with a furnace replacement or in new installations, the duct blower can test first supply then return ducts for airtightness.

Duct-induced room pressures

An improperly balanced air-handling system can reduce comfort, building durability, and indoor air quality. Duct-induced room pressures can increase air leakage through the building shell from 1.5 to 3 times, compared to when the air handler is off.

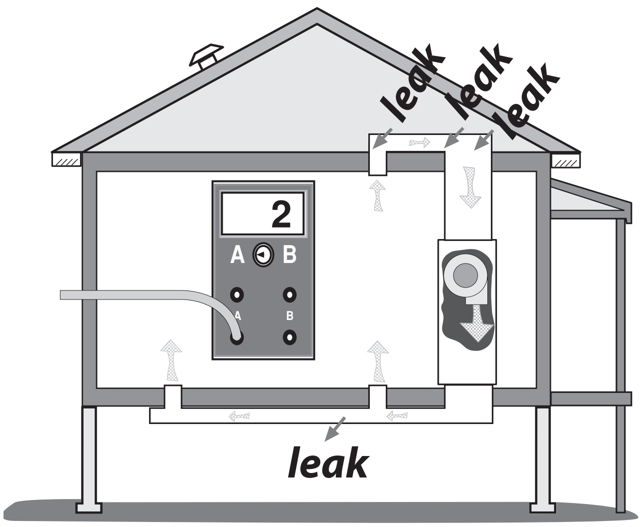
The following test measures pressure differences between the main body of the house and outdoors, between each room and outdoors, and between the combustion zone and outdoors. A pressure difference greater than +4.0 pascals or more negative than –4.0 pascals should be corrected. If the pressure imbalance is the result of occupant behavior such as covering supply or return grilles, discuss these issues with the client.

Dominant duct leakage

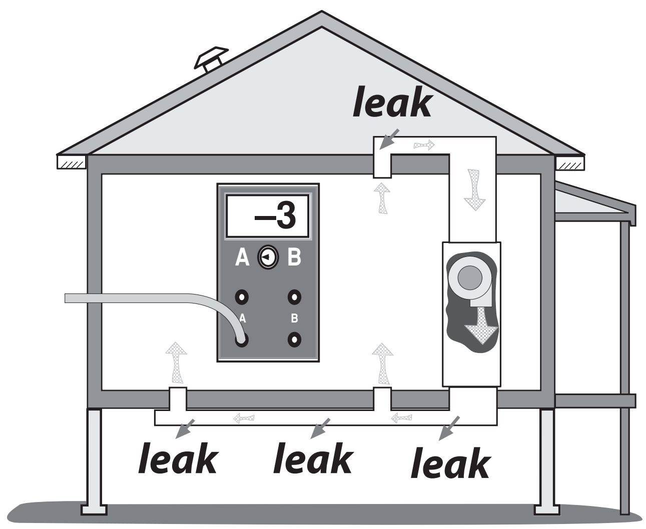
This test helps determine whether sealing efforts should be directed to the supply or return system. It does not measure the amount of leakage present.

1. Set up house for winter conditions. Close all windows and exterior doors. Turn-off all exhaust fans.
2. Open all interior doors, including door to basement.
3. Turn on the air handler.
4. Measure the house-to-outdoors pressure difference.

A positive pressure indicates that the return ducts (which pull air from leaky intermediate zones) are leakier than the supply ducts. A negative pressure indicates that the supply ducts (which push air into intermediate zones through their leaks) are leakier than return ducts. A pressure at or near zero indicates equal supply and return leakage or else little duct leakage.



Dominant return leaks: When return leaks are larger than supply leaks, the house shows a positive pressure with reference to the outdoors.

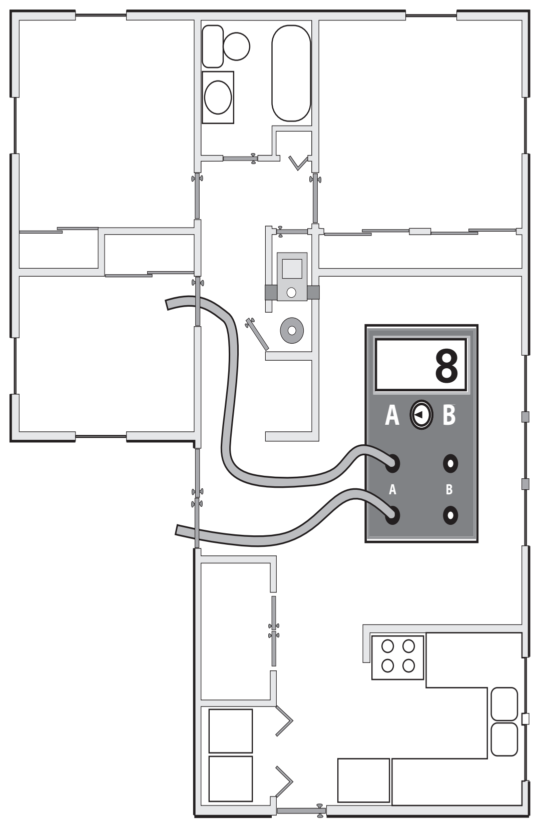


Dominant supply leaks: When supply leaks are larger than return leaks, the house shows a negative pressure with reference to the outdoors.

Room pressure imbalance

1. Leave the house in winter conditions, and leave the air handler running.
2. Close interior doors.
3. Place hose from input tap on the manometer under one of the closed interior doors. Leave reference tap connected to outdoors.
4. Read and record this pressure measurement for each room. This pressure's magnitude indicates the degree to which the air-handler's airflow is unbalanced between supply and return.

If the pressure difference is more than ± 4.0 pascals with the air handler operating, pressure relief is necessary. To estimate the amount of pressure relief, slowly open door until pressure difference drops to between +4.0 pascals and –4.0 pascals. Estimate area of open door. This is the area required to provide pressure relief. Pressure relief may include undercutting the door or installing transfer grilles. *See section 2.7.*



Blocked return path: With interior doors closed, the large positive pressure in the bedroom is caused by the lack of a air return register in the bedroom. The airflow in this forced-air system is unbalanced, creating this pressure, and forcing room air through the room's air leaks.

SECTION 3 - MECHANICAL SYSTEMS

SUBJECTS COVERED IN THIS SECTION

3.1 Assessing Appliance Venting

Proper venting is essential to the operation, efficiency, safety, and durability of combustion appliances. The National Fire Protection Association (NFPA) and the International Code Council (ICC) are the authoritative information sources on material-choice, sizing, and clearances for chimneys and vent connectors. The information in this venting section is based on the following NFPA and ICC documents.

- The *International Fuel Gas Code* (IFGC) (ICC)
- NFPA 31: *Standard for the Installation of Oil-Burning Equipment*
- NFPA 211: *Standard for Chimneys, Fireplaces, Vents, and Solid-Fuel-Burning Appliances*
- The *International Mechanical Code* (IMC) 2000 edition
- The *International Residential Code* (IRC) 2000 edition

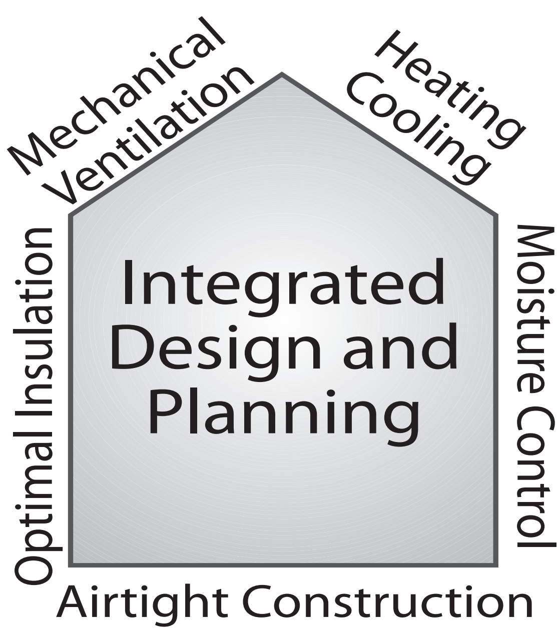


Table 3.1.1: Guide to Venting Standards

Topic	Standard and Section
Vent Sizing	IFGC, Section 504
Clearances	IFGC, Section 308 and Tables 308.2I NFPA 31, Section 4-4.1.1 and Tables 4-4.1.1 and 4-4.1.2 NFPA 211, Sections 6.5, 4.3, 5
Combustion Air	IFGC, Section 304 IMC, Chapter 7 IRC, Chapter 17 NFPA 31, Section 1-9; NFPA 211, Section 8.5 and 9.3

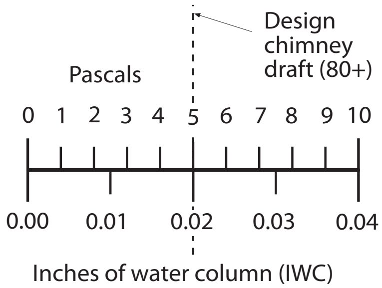
Measuring draft

The majority of existing combustion appliances still exhaust their gases into an atmospheric chimney. An atmospheric chimney produces negative draft—a slight vacuum. The strength of this draft is determined by the chimney's height, its cross-sectional area, and the temperature difference between the flue gases and outdoor air. Atmospheric chimney draft should always be negative.

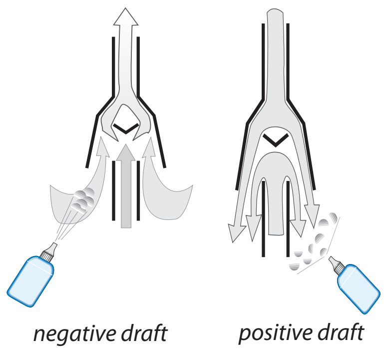
The main purpose of measuring draft is to ensure that the combustion gases are being vented out of a home. Draft is also an indicator of the effectiveness of the venting system and the stability of the combustion process. Draft is measured in inches of water column (IWC) or pascals.

Atmospheric chimneys transport combustion gases using the flame's heat and gases' buoyancy. Atmospheric gas appliances are designed to operate at a chimney draft of around negative 0.02 inches of water column (IWC) or –5 pascals. Tall chimneys located indoors typically produce stronger drafts, and short chimneys or outdoor chimneys produce weaker drafts. Wind and house pressures have a strong influence on draft in atmospheric chimneys.

Fan-assisted appliances employ a small fan near the exhaust of their heat exchanger. This draft-inducing fan regulates the overfire draft but has little or no effect on draft in their atmospheric chimneys.



Positive-draft appliances, like condensing furnaces, have a strong positive draft and an airtight venting system. The positive draft of these appliances is created by a draft fan and is strong enough to resist the influence most indoor and outdoor pressures.

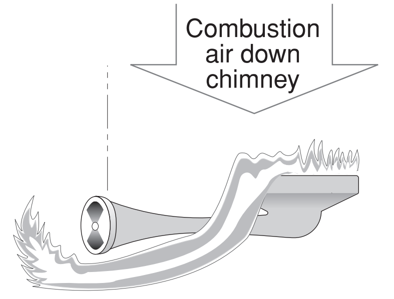


Negative versus positive draft: With positive draft air flows down the chimney and out the draft diverter. A smoke bottle helps distinguish between positive and negative draft in atmospheric chimneys.

Worst-case Draft and Pressure Test

Depressurization is the leading cause of backdrafting and flame roll-out. This test uses the home's exhaust fans, air handler, and chimneys to create worst-case depressurization in the combustion-appliance zone (CAZ). The CAZ is an area containing one or more combustion appliances, such as furnaces, water heaters, wood stoves or fireplaces. During this worst-case testing, you can measure the chimney draft and/or indoor-outdoor pressure difference.

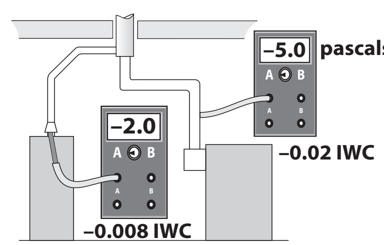
Worst-case conditions do occur, and chimneys should vent their combustion gases even under these extreme conditions. Worst-case draft testing will discover whether or not the venting system will exhaust the combustion gases when the combustion-zone pressure is as negative as you can make it. A sensitive digital manometer is usually used for accurate and reliable readings of both combustion-zone depressurization and chimney draft.



Flame roll-out: Flame roll-out, a serious fire hazard, can occur when the chimney is blocked, the combustion zone is depressurized, or during very

Draft-only worst-case testing

Since draft tells us whether combustion gases are being exhausted, we can measure draft and note how it is affected by potential backdrafting causes such as exhaust fans, furnace blower operation, and opening and closing interior doors. This short test works well for finding simple draft problems.



Worst-case draft testing: Measure draft for atmospheric gas appliances at worst-case conditions to ensure proper venting. Draft is measured on the chimney side of the draft diverter. For oil appliances, measure draft between the barometric draft control and the appliance.

1. Measure draft in the furnace and water heater, starting at burner light-off until blower activation. Draft should be negative and growing stronger as the furnace heats up. Does activation of the furnace blower weaken draft?
2. Continue to measure draft in the furnace and water heater while activating exhaust fans and clothes dryer. Open and close

interior doors. Is the draft weakened by any of these activities? Does draft ever go to 0 or into the positive range?

Draft testing with CAZ depressurization

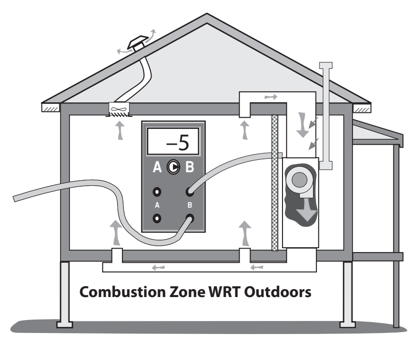
For trickier draft problems, it helps to measure the CAZ depressurization in addition to draft. Start the testing by turning on combustion appliances and exhaust fans. With exterior doors and windows closed, connect a digital manometer to read the pressure difference between combustion zone and outdoors. Then take the following steps and measurements.

1. Record the CAZ-to-outdoors pressure difference with the CAZ door open. Then close the door and measure the pressure difference again. Whatever negative pressure you measure is caused by the combustion appliances and exhaust appliances. If opening a window or door to outdoors reduces or eliminates the negative pressure, combustion or make-up air may be needed.
2. Next, turn on the air handler. Then measure the CAZ-to-outdoors pressure difference again—first with the CAZ door closed, then with it open. Negative pressure or increased negative pressure (compared to Step 1) is caused by the furnace blower and return ducts.
3. Now, close all interior doors; measure the CAZ-to-outdoors pressure difference again—first with the CAZ door closed then with it open. Negative pressure or increased negative pressure (compared to Step 2) is caused by imbalanced airflow between supply and return registers.
4. Finally, recreate the conditions observed in steps 1 through 3 above that produced the highest negative pressure. Measure actual worst-case draft for all appliances under these conditions. When there are multiple combustion appliances, operate them separately and together. Measure draft in each appliance and compare the negative draft to the values in the table shown below.

Table 3.1.2: Guide to Venting Standards

Topic	Standard and Section
Vent Sizing	IFGC, Section 504
Clearances	IFGC, Section 308 and Tables 308.2I NFPA 31, Section 4-4.1.1 and Tables 4-4.1.1 and 4-4.1.2 NFPA 211, Sections 6.5, 4.3, 5
Combustion Air	IFGC, Section 304 IMC, Chapter 7 IRC, Chapter 17 NFPA 31, Section 1-9; NFPA 211, Section 8.5 and 9.3

5. If the home has a wood-burning fireplace, simulate a 300 cfm chimney exhaust with the blower door, and repeat the conditions and measurements of Step 4 above. If the home has a wood stove or other solid-fuel appliance, perform a depressruization test in that CAZ.



A reading more negative than –5 pascals indicates a significant possibility of backdrafting.

Worst-case depressurization: Worst-case testing is used to identify problems that weaken draft and restrict combustion air. The testing described here is intended to isolate the negative-pressure source.

Take all necessary steps to identify and remove excessive negative house pressures and to improve draft to minimum standards. *See Table 3.1.3.*

Monitor ambient CO levels during draft testing, especially if CAZ depressurization exceeds –5 pascals during testing. If ambient CO levels in the combustion zone exceed 20 parts per million (ppm), draft tests should cease for the technician’s safety. The CAZ should be ventilated before draft-testing and diagnosis of CO problems resumes.

Table 3.1.3: Minimum Worst-Case Draft

Appliance	Outdoor Temperature (Degrees F) <20	21-40	41-60	61-80	>80
Gas-fired furnace, boiler, or water heater with atmospheric chimney	–5 Pa. –0.02 IWC	– 4 Pa. –0.016 IWC	–3 Pa. –0.012 IWC	–2 Pa. –0.008 IWC	–1 Pa. –0.004 IWC
Oil-fired furnace, boiler, or water heater with atmospheric chimney	–15 Pa. –0.06 IWC	–13 Pa. –0.053 IWC	–11 Pa. –0.045 IWC	–9 Pa. –0.038 IWC	–7 Pa. –0.030 IWC

IMPROVING INADEQUATE DRAFT

If measured draft is below minimum draft pressures, investigate the reason for the weak draft. Open a window or door to observe whether the addition of combustion air will improve draft. If this added air strengthens draft, the problem usually is depressurization. If opening a window has no effect, inspect the chimney. The chimney could be blocked or excessively leaky.

Chimney improvements to solve draft problems

- ✔ Remove chimney obstructions.
- ✔ Repair disconnections or leaks at joints and where the vent connector joins a masonry chimney.
- ✔ Measure the size of the vent connector and chimney and compare to vent-sizing information listed in Section 504 of the *International Fuel Gas Code*. A vent connector or chimney liner that is either too large or too small can result in poor draft.
- ✔ If wind is causing erratic draft, consider installing a wind-dampening chimney cap.
- ✔ If the masonry chimney is deteriorated, consider installing a new chimney liner. *See section 3.2.*
- ✔ Increase the pitch of horizontal vent sections.

Table 3.1.4: Draft Problems and Solutions

Problem	Possible Solutions
Adequate draft never established	Remove chimney blockage, seal chimney air leaks, or provide additional combustion air as necessary.
Blower activation weakens draft	Seal leaks in the furnace and in nearby return ducts. Isolate the furnace from nearby return registers.
Exhaust fans weaken draft	Provide make-up or combustion air if opening a door or window to outdoors strengthens draft during testing.
Closing interior doors during blower operation weakens draft	Add return ducts, grills between rooms, or jumper ducts.

Duct improvements to solve draft problems

- ✔ Repair all return-duct leaks near furnace.
- ✔ Isolate furnace from return registers by air-sealing.
- ✔ Improve balance between supply and return air by installing new return ducts, transfer grills, or jumper ducts. *See section 3.6.*

Reducing depressurization from exhaust devices

- ✔ Isolate furnace from exhaust fans and clothes dryers by air-sealing between the CAZ and zones containing these devices.
- ✔ Reduce the capacity of large exhaust fans.

Combustion and make-up air

- ✔ Provide make-up air for dryers and exhaust fans and/or provide combustion-air inlet(s) to combustion zone. *See section 3.3.*

3.2 Venting Combustion Gases

Combustion gases are vented through vertical chimneys or other types of approved horizontal or vertical vent piping. Identifying the type of existing venting material, verifying the correct size of vent piping, and making sure the venting conforms to the applicable codes are important tasks in inspecting and repairing venting systems. Too large a vent often leads to condensation and corrosion. Too small a vent can result in spillage. The wrong vent materials can corrode or deteriorate from heat.

Vent connectors

A vent connector connects the appliance's venting outlet with the chimney. Approved vent connectors for gas- and oil-fired units are made from the following materials.

1. Type-B vent, consisting of a galvanized-steel outer pipe and aluminum inner pipe
2. Type-L vent connector with a stainless-steel inner pipe and either galvanized or black-steel outer pipe.
3. Galvanized-steel pipe (≥ 0.019 inch thick or 20 gauge) for vent connectors 5 inches in diameter or less.
4. Galvanized-steel pipe (≥ 0.023 inch thick or 22 gauge) for vent connectors 6-to-10 inches in diameter.

Double-wall vent connectors are the best option, especially for appliances with some horizontal vent piping. A double-wall vent connector helps maintain flue-gas temperature and prevent condensation. Gas appliances with draft hoods, installed in attics or crawl spaces must use a Type-B vent connector. Type-L vent pipe is commonly used for vent connectors for oil and solid fuels but can also be used for gas.

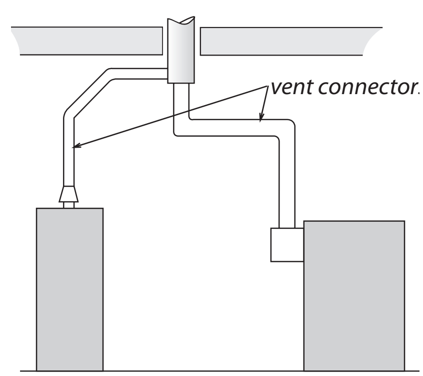
Observe the following general specifications, concerning vent connectors.

- A vent connector is almost always the same size as the vent collar on the appliance it vents.
- Single-wall vent-pipe sections should be fastened together with 3 screws or rivets.
- The vent connector should be sealed tightly where it enters a masonry chimney.
- Vent connectors should be free of rust, corrosion and holes.
- The chimney combining two vent connectors should have a cross-sectional area equal to the area of the larger vent connector plus half the area of the smaller vent connector. This common vent should be no larger than 7 times the area of the smallest vent. For specific vent sizes are listed in NFPA codes. *See section 3.1.*

Table 3.2.1: Areas of Round Vents

Vent diameter	4"	5"	6"	7"	8"
Vent area (square inches)	12.6	19.6	28.3	38.5	50.2

- The horizontal length of vent connectors shouldn't be more than 75% of the chimney's vertical height or have more than 18 inches horizontal run per inch of vent diameter.



Two vent connectors joining chimney: The water heater's vent connector enters the chimney above the furnace because the water heater has a smaller input.

- Vent connectors must have upward slope to their connection with the chimney. A slope of at least $^1/_4$ inch of rise per foot of horizontal run along their entire length is recommended to cause combustion gases to rise through the vent and to prevent condensation from pooling and rusting the vent.

Table 3.2.2: Vent Connector Diameter vs. Maximum Horizontal Length

Diam. (in)	3"	4"	5"	6"	7"	8"	9"	10"	12"	14"
Length (ft)	4.5'	6'	7.5'	9'	10.5'	12'	13.5'	15'	18'	21'
From *International Fuel Gas Code 2000*										

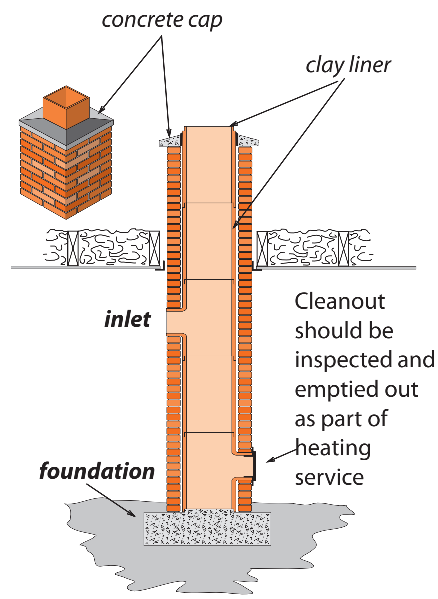
- When two vent connectors connect to a single chimney, the vent connector servicing the smaller appliance should enter the chimney above the vent for the larger appliance.
- Clearances for common vent connectors are listed in the following table.

Table 3.2.3: Clearances to Combustibles for Common Vent Connectors

Vent Connector Type	Clearance
Single-wall galvanized-steel vent pipe	6" (gas) 18" (oil)
Type-B double-wall vent pipe (gas)	1" (gas)
Type L double wall vent pipe (stainless steel inner liner, stove pipe or galvanized outer liner)	9", or 1 vent diameter, or as listed

CHIMNEYS

There are two common types of vertical chimneys for venting combustion fuels that satisfy NFPA and ICC codes. First there are masonry chimneys lined with fire-clay tile, and second there are manufactured metal chimneys, including all-fuel metal chimneys and Type-B vent chimneys for gas appliances.



Masonry chimneys: Remain a very common vent for all fuels.

Masonry chimneys

Observe the following general specifications for building, inspecting, and repairing masonry chimneys.

- Masonry chimneys should be supported by their own masonry foundation.
- Existing masonry chimneys should be lined with a fireclay flue liner. There should be a $^1/_2$-inch to 1-inch air gap between the clay liner and the chimney's masonry to insulate the liner. The liner shouldn't be bonded structurally to the outer masonry because it needs to expand and contract independently of the chimney's masonry structure. The clay liner can be sealed to the chimney cap with a flexible high-temperature sealant.
- The chimney's penetrations through floors and ceilings should be sealed with metal and high-temperature sealant as a firestop and air barrier.

- Deteriorated or unlined masonry chimneys should be rebuilt as specified above or relined as part of a heating-system replacement or a venting-safety upgrade. As an alternative, the vertical chimney may be replaced by a sidewall vent, equipped with a power venter mounted on the exterior wall.

Table 3.2.4: Clearances to Combustibles for Common Chimneys

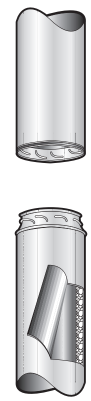
Chimney Type	Clearance
Interior chimney masonry w/ fireclay liner	2"
Exterior masonry chimney w/ fireclay liner	1"
All-fuel metal vent: insulated double wall or triple-wall pipe	2"
Type B double-wall vent (gas only)	1"
Manufactured chimneys and vents list their clearance	

- Masonry chimneys should have a cleanout 12 inches or more below the lowest inlet. Mortar and brick dust should be cleaned out of the bottom of the chimney through the clean-out door, so that this debris won't eventually interfere with venting.

Manufactured chimneys

Manufactured metal chimneys have engineered parts that fit together in a prescribed way. Metal chimneys contain manufactured components from the vent connector to the termination fitting on the roof. Parts include: metal pipe, weight-supporting hardware, insulation shields, roof jacks, and chimney caps. One manufacturer's chimney may not be compatible with another's connecting fittings.

All-fuel metal chimneys come in two types: insulated double wall metal pipe and triple-wall metal pipe. Install them strictly observing the manufacturer's specifications.

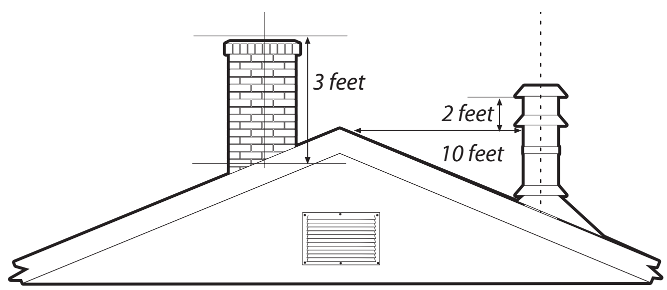


All-fuel metal chimney: These chimney systems include transition fittings, support brackets, roof jacks, and chimney caps. The pipe is double-wall insulated or triple wall.

Type-B vent pipe is permitted as a chimney for gas appliances. Some older manufactured gas chimneys were made of metal-reinforced asbestos cement.

Chimney termination

Masonry chimneys and all-fuel metal chimneys should terminate at least three feet above the roof penetration and two feet above any obstacle within ten feet of the chimney outlet. Chimneys should have a cap to prevent rain and strong downdrafts from entering.



Chimney terminations: Should have vent caps and be given adequate clearance height from nearby building parts. These requirements are for masonry chimneys and manufactured all-fuel chimneys.

B-vent chimneys can terminate as close as one foot above flat roofs and pitched roofs up to a $^{6}/_{12}$ roof pitch. As the pitch rises, the minimum termination height rises as shown in the table.

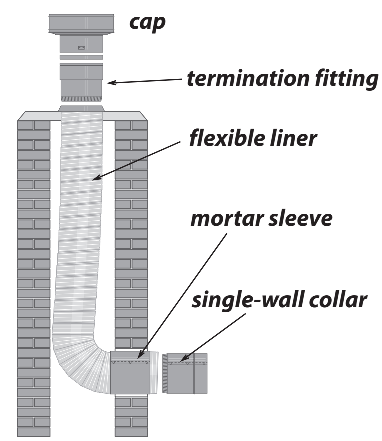
Table 3.2.5: Roof Slope and B-Vent Chimney Height (feet) Above Roof

flat-6	6/12-7/12	7/12-8/12	8/12-9/12	9/12-10/12	10/12-11/12	11/12-12/12	12/12-14/12	14/12-16/12	16/12-18/12
1'	1' 3"	1' 6"	2'	2' 6"	3' 3"	4'	5′	6'	7'

From *International Fuel Gas Code 2000*

Metal liners for masonry chimneys

Unlined masonry chimneys or chimneys with deteriorated liners should be relined as part of heating system replacement. Use either Type-B vent, a flexible or rigid stainless-steel liner, or a flexible aluminum liner. *See "Power venters for sidewall venting" in this section.*



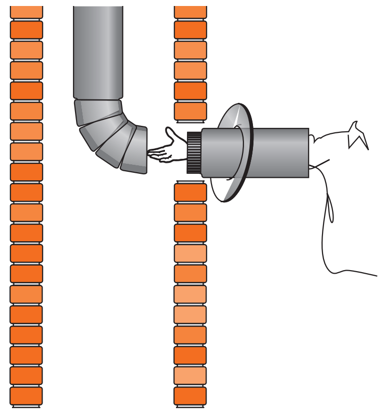
Flexible metal chimney liners: The most important installation issues are sizing the liner correctly along with fastening and supporting the ends to prevent sagging.

Flexible liners require careful installation to avoid a low spot at the bottom, where the liner turns a right angle to pass through the wall of the chimney. Follow the manufacturer's instructions, which usually prescribe stretching the liner and fastening it securely at both ends, to prevent it from sagging and thereby creating such a low spot.

Flexible liners are easily damaged by falling masonry debris inside a deteriorating chimney. Use B-vent instead of a flexible liner when the chimney is significantly deteriorated.

To minimize condensation, flexible liners should be insulated—especially when installed in exterior chimneys. Consider insulating flexible metal chimney liners with vermiculite or a fiberglass-insulation jackets, if the manufacturer's instructions allow.

Sizing flexible chimney liners correctly is very important. Oversizing is common and can lead to condensation and corrosion. The manufacturers of the liners include vent-sizing tables in their instructions. Liners should bear the label of a testing lab like Underwriters Laboratories (UL).



B-vent chimney liner: Double-wall Type-B vent is the most commonly available chimney liner and is recommended over flexible liners. Rigid stainless-steel single-wall liners are also a permanent solution to deteriorated chimneys.

Special venting considerations for gas

The American Gas Association (AGA) has devised a classification system for venting systems serving natural gas and propane appliances. This classification system assigns Roman numerals to four categories of venting based on whether there is positive or negative pressure in the vent and whether condensation is likely to occur in the vent.

A great majority of appliances found in homes and multifamily buildings are Category I, which have

	Negative-pressure Venting	Positive-pressure
Non-condensing	I Combustion Efficiency **83% or less** Use standard venting: masonry or Type B vent	III Combustion Efficiency **83% or less** Use only pressurizable vent as specified by manufacturer
Condensing	II Combustion Efficiency **over 83%** Use only special condensing-service vent as specified by manufacturer	IV Combustion Efficiency **over 83%** Use only pressurizable condensing-service vent as specified by manufacturer

American Gas Association Vent Categories

AGA venting categories: The AGA classifies venting by whether there is positive or negative pressure in the vent and negative pressure in vertical chimneys with no condensation expected in the vent connector or chimney. Condensing furnaces are usually Category IV with positive pressure in their vent and condensation occurring in both the appliance and vent. Category III vents are rare but some fan-assisted appliances are vented with airtight non-condensing vents.

Venting fan-assisted furnaces and boilers

Newer gas-fired fan-assisted central heaters control flue-gas flow and excess air better than atmospheric heaters, resulting in their higher efficiency. These are non-condensing Category I furnaces in the 80%-plus Annual Fuel Utilization Efficiency (AFUE) range. Because these units eliminate dilution air and have slightly cooler flue gases, existing chimneys should be carefully inspected to ensure that they are ready for a possibly more corrosive flue-gas flow. The chimney should be relined when any of the following three conditions are present.

1. When the existing masonry chimney is unlined.
2. When the old clay or metal chimney liner is deteriorated.
3. When the new heater has a smaller input than the old one. In this case the liner should be sized to the new furnace or boiler and the existing water heater.

For gas-fired 80+ AFUE furnaces, a chimney liner should consist of:

- Type-B vent
- A rigid or flexible stainless steel liner
- A poured masonry liner
- An insulated flexible aluminum liner

Because of the considerable expense that chimney relining can entail, sidewall venting with a power venter should be considered when an existing chimney is inadequate for new appliances.

Table 3.2.6: Gas Furnace and Boiler Characteristics

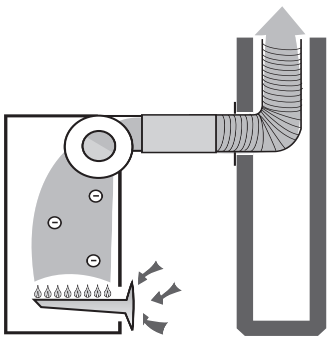
Steady-state efficiency	Operating characteristics
70+	Category I, draft diverter, no draft fan, standing pilot, non-condensing, indoor combustion and dilution air.
80+	Category I, no draft diverter, draft fan, electronic ignition, indoor combustion air, no dilution air.
90+	Category IV, no draft diverter, draft fan, low-temperature plastic venting, positive draft, electronic ignition, condensing heat exchanger, outdoor combustion air is strongly recommended.

Pressurized sidewall vents

Sometimes, the manufacturer gives the installer a venting choice of whether to install a fan-assisted furnace or boiler into a vertical chimney (Category I) or as a positive-draft appliance (Category III), vented through a sidewall vent. Sidewall-vented fan-assisted furnaces and boilers may vent through B-vent, stainless-steel single-wall vent pipe, or high-temperature plastic pipe. Pressurized sidewall vents should be virtually airtight at the operating draft. B-vent must be sealed with high-temperature silicone caulking or other approved means to air-seal its joints.

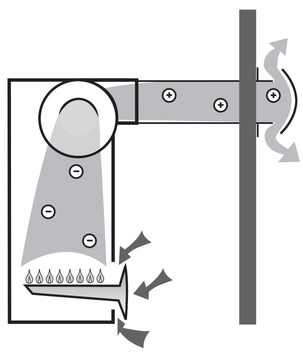
Some high-temperature positive-draft plastic vent pipe, used in horizontal installations, was recalled by manufacturers because of deterioration from heat and condensation. Deteriorated high-temperature plastic vent should be replaced by airtight stainless-steel vent piping or else B-vent, sealed at joints with high-temperature sealant.

Existing fan-assisted appliances may have problems with weak draft and condensation when vented horizontally. Horizontally vented, fan-assisted furnaces and boilers may require a retrofit power venter to create adequate draft in some cases.



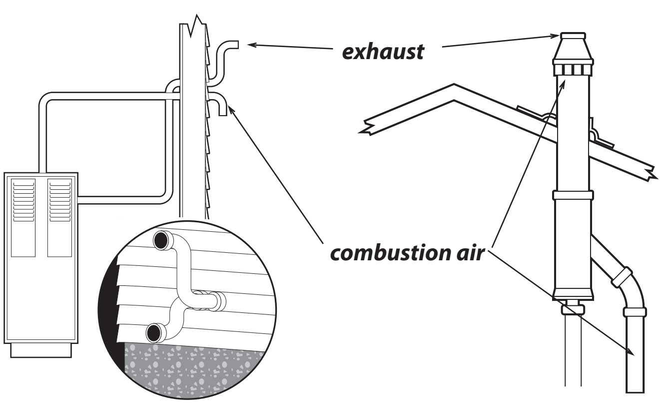
Fan-assisted gas heaters with vertical chimneys: These 80% AFUE central heaters are almost always vented into atmospheric chimneys, which may need to be relined.

Fan-assisted heaters with sidewall vents: Sometimes these appliances are vented through a side wall through airtight plastic or stainless-steel vent pipe.



Condensing-furnace venting

Condensing furnaces with 90+ AFUE are vented horizontally or vertically through PVC Schedule 40 pipe. The vent is pressurized and plenty of condensation occurs, making it Category IV. Vent piping should be sloped back toward the appliance, so the condensate can be drained and treated if necessary.

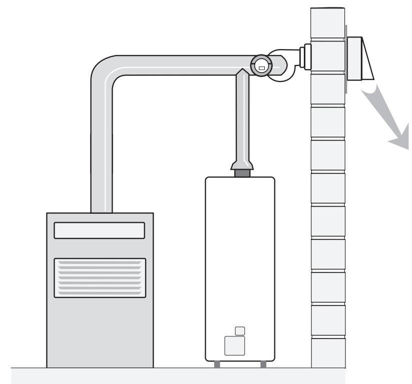


Condensing furnace venting: The two common types of termination for plastic condensing vents are separate pipes and a combined fitting. Vents going through the roof are preferred for their being more resistant to tampering and damage.

Combustion air is supplied from outdoors through a sealed plastic pipe or from indoors. Outdoor combustion air is highly recommended, and most condensing furnaces are equipped for outdoor combustion air through a dedicated pipe. This combined combustion-air and venting system is referred to as direct-vent or sealed-combustion.

Power venters for sidewall venting

Power venters are installed just inside or outside an exterior wall and are used for sidewall venting. Power venters create a stable negative draft.



Power venters: Sidewall venting with a power venter is an excellent option when the chimney is dilapidated or when no chimney exists.

Many power venters allow precise control of draft through air controls on the their fans. Barometric draft controls can also provide good draft control when installed either on the common vent for two-appliances or on the vent connector for each appliance. This more precise draft control, provided by the power venter and/or barometric damper, minimizes excess combustion and dilution air. Flue gas temperatures for power venters can be cooler than temperatures needed to power vertical atmospheric chimneys. Less excess air and cooler flue gases can improve combustion efficiency in many cases, compared to the non-adjustable draft of a vertical chimney. However, the power venter must be installed by a technician familiar with adjusting the draft to each appliance to achieve the efficiency benefit.

A single power venter can vent both a furnace or boiler and also a water heater. Types B or L vent are good choices for horizontal vent piping. Use Type B for gas only.

Power venters should be considered as a venting option when:

- Wind, internal house pressures, or nearby buildings have created a stubborn drafting problem that other options can't solve.

- An existing horizontally vented appliance has weak draft and/or condensation problems.
- Clients who currently heat with electricity want to convert to gas space heating and water heating but have no chimney.
- The cost of lining an unlined or deteriorated chimney exceeds the cost of installing a power venter with its horizontal vent.
- A floor furnace or other appliance with a long horizontal vent connector has backdrafting problems.
- A water heater is orphaned in a too-large vertical chimney when the new furnace or boiler is vented through a plastic venting system.
- High draft in the existing vertical chimney is creating unstable combustion or low steady-state efficiency in the appliances connected to it.

3.3 Combustion Air

Combustion air enters the combustion appliance zone (CAZ) through unintentional or intentional openings in the building shell or through a dedicated pipe from outdoors. The need to install an outdoor combustion air source is a common decision in residential HVAC installation and service work. Use worst-case draft testing to help determine whether or not to improve combustion air. *See section 3.1.*

The goals of assessing combustion air through draft testing are the following.

- To discover whether or not there is an adequate supply of combustion air.
- To ensure that a combustion-air problem isn't creating CO, weakening draft, or interfering with combustion.
- To avoid unnecessary work or creating a problem by installing combustion air openings. Combustion air openings can depressurize the CAZ in some cases, especially when the openings are above the furnace or boiler.

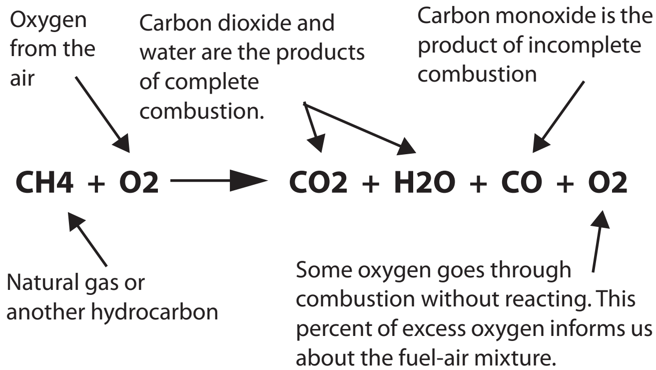
A combustion-air source must deliver between 17 cfm and 600 cfm, depending on the size of the combustion appliances.

A combustion appliance zone (CAZ) is classified as either an un-confined space or confined space. An un-confined space is a CAZ connected to enough building air leakage to provide combustion air. A confined space is a CAZ with sheeted walls and ceiling and a closed door that form an air barrier between the appliance and other indoor spaces. For confined spaces, the IFGC prescribes additional combustion air from outside the CAZ. Combustion air is supplied to the combustion appliance in four ways.

1. To an un-confined space through leaks in the building.
2. To a confined space through an intentional opening or openings between the CAZ and other indoor areas where air leaks replenish combustion air.
3. To a confined space through an intentional opening or openings between the CAZ and outdoors or ventilated intermediate zones like attics and crawl spaces.
4. Directly from the outdoors to the combustion appliance through a duct. Appliances with direct combustion-air ducts are called sealed-combustion or direct-vent appliances.

Table 3.3.1: CFM Air Requirements for Combustion Furnaces or Boilers

Appliance	Combustion Air (cfm)	Dilution Air (cfm)
Conventional Oil	38	195
Flame-Retention Oil	25	195
High-Efficiency Oil	22	–
Conventional Atmospheric Gas	30	143
Fan-Assisted Gas	26	–
Condensing Gas	17	–
Fireplace (no doors)	100–600	–
Airtight Wood Stove	10–50	–
A.C.S. Hayden, Residential Combustion Appliances: Venting and Indoor Air Quality Solid Fuels Encyclopedia		



UN-CONFINED-SPACE COMBUSTION AIR

Combustion appliances located in most basements, attics, and crawl spaces get adequate combustion air from leaks in the building shell. Even when a combustion appliance is located within the home's living space, it usually gets adequate combustion air from air leaks unless the house is airtight or the combustion zone is depressurized. *See section 3.1.*

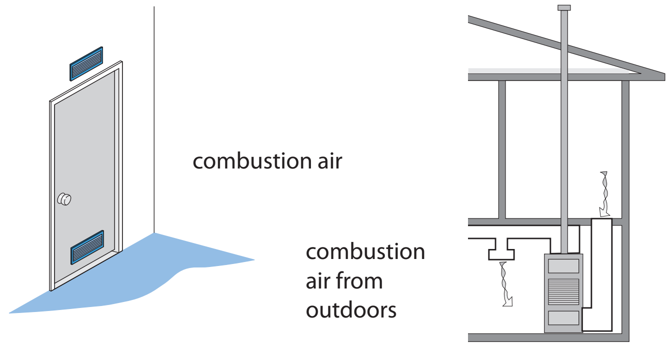
CONFINED-SPACE COMBUSTION AIR

A confined space is defined by the IFGC as a room containing one or more combustion appliances that has less than 50 cubic feet of volume for every 1000 Btu per hour of appliance input.

However, if a small mechanical room is connected to adjacent spaces through large air passages like floor-joist spaces, the CAZ may not need additional combustion air despite sheeted walls and a door separating it from other indoor spaces. The extent of the connection between the CAZ and other spaces can be confirmed by worst-case draft testing or blower-door pressure testing.

On the other hand, if the home is unusually airtight, the CAZ may be unable to provide adequate combustion air, even when the combustion zone is larger than the minimum confined-space room volume, defined above.

Combustion air from adjacent indoor spaces is usually preferred over outdoor combustion air because of the possibility of wind depressurizing the combustion zone. However, if there is a sheltered outdoor space from which to draw combustion air, outdoor combustion air may be a superior choice. Outdoor air is generally cleaner and dryer than indoor air, and a connection to the outdoors makes the confined space less affected by indoor pressure fluctuations.



Passive combustion-air options: Combustion air can be supplied from adjacent indoor spaces or from outdoors. Beware of passive combustion-air vents into the attic that could depressurize the combustion zone or allow moisture to travel into the attic.

In confined spaces or airtight homes where outdoor combustion air is needed, prefer a single vent openings installed as low in the CAZ as practical. A combustion-air vent into an attic may depressurize the combustion zone or dump warm moist air into the attic. Instead, connect the combustion zone to a ventilated crawl space or directly to outdoors through a single low vent if possible.

Choose an outdoor location that is sheltered, where the wall containing the vent isn't parallel to prevailing winds. Wind blowing parallel to an exterior wall or at a right angle to the vent opening tends to depressurize both the opening and the CAZ connected to it. Indoors, locate combustion air vents away from water pipes to prevent freezing in cold climates.

Table 3.3.2: Combustion Air Openings: Location and Size

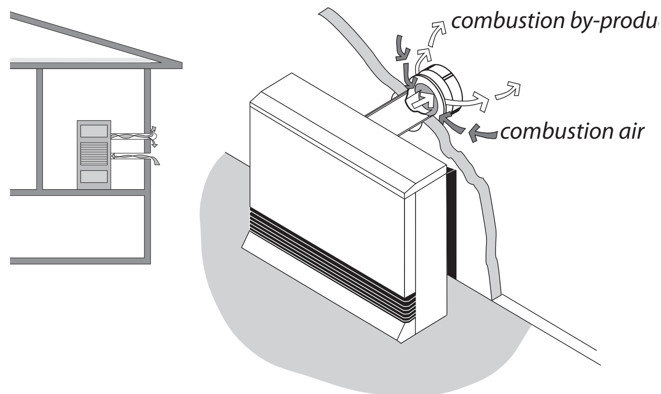
Location	Dimensions
Two direct openings to adjacent indoor space	Each vent should have1 in^2 per 1000 Btuh (Minimum area each: 100 in$^{2)}$ Combined room volumes must be ≥ 50 ft^3/1000 Btuh
Two direct openings or vertical ducts to outdoors	Each vent should have 1 in^2 for each 4000 Btuh
Two horizontal ducts to outdoors	Each vent should have 1 in^2 for each 2000 Btuh
Single direct or ducted vent to outdoors	Single vent should have 1 in^2 for each 3000 Btuh
From the International Fuel Gas Code	

Net free area is smaller than actual vent area and takes the blocking effect of louvers into account. Metal grills and louvers provide 60% to 75% of their area as net free area while wood louvers provide only 20% to 25%. Combustion air vents should be no less than 3 inches in their smallest dimension.

Here is an example of sizing combustion air to another indoor area. The furnace and water heater are located in a confined space. The furnace has an input rating of 100,000 Btu/hour. The water heater has an input rating of 40,000 Btu/hour. Therefore, there should be 280 in^2 of net free area of vent between the mechanical room and other rooms in the home. ([100,000 + 40,000] ÷ 1,000 = 140 x 2 in^2 = 280 in^2). Each vent should therefore have a minimum of 140 in^2.

Direct outdoor combustion-air supply

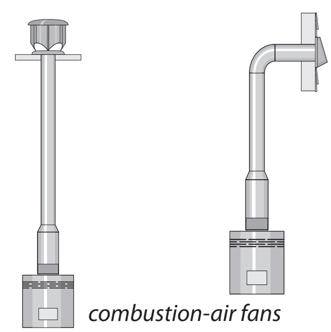
Many new combustion appliances are designed for direct outdoor-air supply to the burner. These include most condensing furnaces, mobile home furnaces, mobile home water heaters, many space heaters, and some non-condensing furnaces and boilers. Some appliances give installers a choice between indoor and outdoor combustion air. Outdoor combustion air is usually preferable in order to prevent the depressurization problems, combustion-air deficiencies, and draft problems.



Sealed combustion: Sealed combustion appliances draw combustion air in and exhaust combustion by-products, either using a draft fan or by pressure differences created by the fire.

Fan-powered combustion air

At least one company manufactures a proprietary combustion-air system that introduces outdoor air through a fan that sits on the floor and attaches to a combustion-air duct to outdoors.



Fan-powered combustion air: Fans for supplying combustion air can help solve stubborn combustion air and drafting problems.

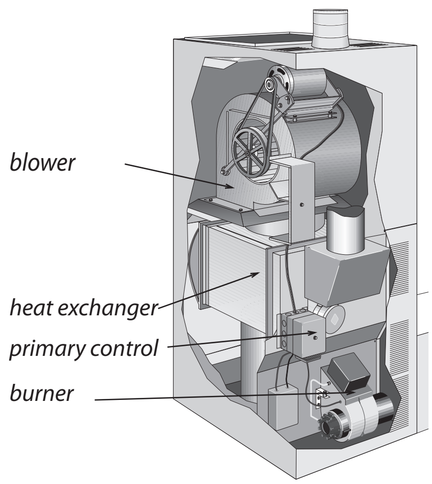
Combustion air combined with power venting

Both gas- and oil-fired heating systems can be supplied with combustion air by proprietary systems that combine power venting with powered combustion-air supply. The combustion air simply flows into the combustion zone from outdoors, powered by the power venter. If the appliance has a power burner, like a gun-type oil burner, a boot may be available to supply combustion air directly to the burner as shown here.

3.4 FURNACE OPERATING STANDARDS

Don't assume that older furnaces are inefficient until testing them. During testing, make appropriate efforts to repair and adjust the existing furnace before deciding to replace it. Replacement parts like gas valves and controls for older heating units are commonly available.

Heating appliances are often replaced when the cost of repairs and retrofits exceeds one half of estimated replacement costs. Estimate the repair and retrofit costs and compare them to replacement cost before deciding between retrofit and replacement.



Oil-fired downflow furnaces: Their design hasn't changed much in recent years except for the flame-retention burner.

New heating appliances must be installed to manufacturer's specifications, following all applicable building and fire codes. Replacement furnaces and boilers should have a minimum Annual Fuel Utilization Efficiency (AFUE) of 80%. However gas furnaces with AFUEs of 90% should be given special consideration. These high-efficiency furnaces are direct-vent, sealed-combustion units with health and safety benefits in addition to their superior efficiency and significantly lower fuel usage.

Heat load calculations, used to size the new heater, should account for reduced heating loads, resulting from insulation and air-sealing work. Heat load calculations should follow Manual J procedures.

The overall system efficiency of an oil or gas forced-air heating system is affected by blower operation, duct leakage, system airflow, balance between supply and return air, and duct insulation levels. Retrofits to the forced-air system generally are more cost-effective than retrofits to the heating unit itself.

The effectiveness of a furnace depends on its heat rise, fan-control temperatures, and flue-gas temperature. For efficiency you want a low heat rise. However, you must maintain a minimum flue-gas temperature to prevent corrosion in the venting of combustion furnaces. Apply the following furnace-operation standards to maximize the heating system's seasonal efficiency and safety.

- Check heat rise after 5 minutes of operation. Refer to manufacturer's nameplate for acceptable heat rise (supply temperature minus return temperature). The heat rise should be between 40°F and 70°F with the lower end of this scale being preferable for energy efficiency.
- All forced-air heating systems must deliver supply air and collect return air only within the intentionally heated portion of the house. Taking return air from an un-heated area of the house such as an unoccupied basement is not acceptable.
- The fan-off temperature should be between 95° and 105° F, with the lower end of the scale being preferable for maximum efficiency.
- The fan-on temperature should be 120-140° F, and the lower the better.
- On time-activated fan controls, verify that the fan is switched on within two minutes of burner ignition and is switched off within 2.5 minutes of the end of the combustion cycle.
- The high-limit controller should shut the burner off before the furnace temperature reaches 200°F.

Table 3.4.1: Furnace Operating Parameters

20°–45°	45°–70°	70°–95°
Inadequate heat rise: condensation and corrosion possible.	Heat rise OK for both efficiency and avoidance of condensation.	Heat rise excessive: Check fan speed, heat exchanger and ducts.

Heat Rise = Supply Temperature – Return Temperature

85°–100°	100°–115°	115°–130°
Excellent fan-off temperature if comfort is acceptable.	Borderline acceptable: Consider replacing fan control.	Unacceptable range: Significant savings possible by adjusting or replacing fan control.

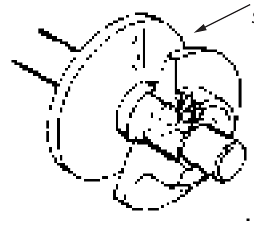
Fan-off Temperature

100°–120°	120°–140°	140°–160°
Excellent fan-on temperature range: No change needed.	Fair: Consider fan-control replacement if fan-off temperature is also borderline.	Poor: Adjust or replace fan control.

Fan-on Temperature

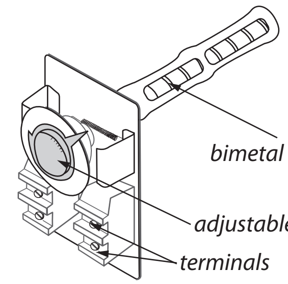
If the heating system does not conform to these standards, consider the following improvements.

- ✔ Clean or change dirty filters. Clean air-conditioning coils.
- ✔ Clean the blower, increase fan speed, and improve ducted air circulation.
- ✔ Adjust fan control to conform to the above standards, or replace the fan control if adjustment fails. Many fan controls on modern furnaces aren't adjustable.
- ✔ Adjust the high-limit control to conform to the above standards, or replace the high-limit control.
- After adjustments, measured flue-gas temperature should be no lower than manufacturer's specifications or the listed minimum values in *Table 3.4.3.*

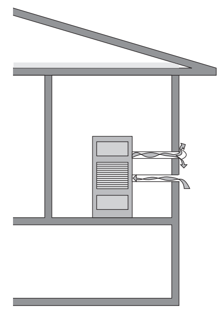


Adjustable drive pulley: This adjustable pulley moves back and forth allowing the belt to ride higher or lower, adjusting the blower's speed.

A fan/limit control: Turns the furnace blower on and off, according to temperature. Also turns the burner off if the heat exchanger gets too hot (high limit).



Furnace replacement



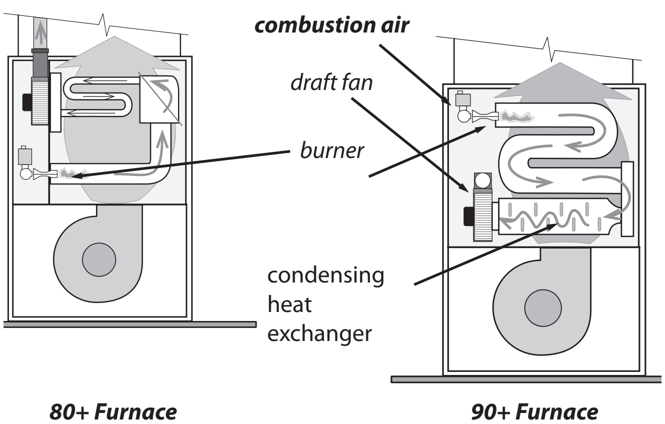
Sealed combustion heaters: Sealed combustion furnaces and boilers prevent the air pollution and house depressurization caused by some open-combustion heating units.

The overall goal of the system replacement is to provide a gas-fired heating system in virtually new condition, even though existing components like the gas lines, chimney, water piping, or ducts may remain. Any necessary maintenance or repair on these remaining components should be considered part of the installation. Any design flaws in the original system should be diagnosed and corrected during the heating-system replacement. Additional information on hot-water space heating is given on *See section 3.9.* Additional information on forced air furnaces is listed. *See section 3.4.*

Observe the following standards in furnace installation.

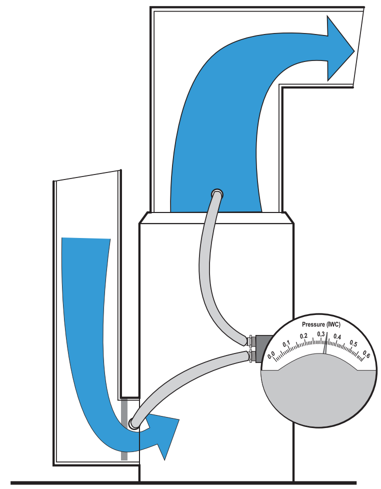
- ✔ Furnace should be sized to the approximate heating load of the home, accounting for post-weatherization heat-loss reductions.

- ✔ Installer should add return ducts or supply ducts as part of furnace replacement to improve air distribution, to eliminate duct-induced house pressures, and to establish acceptable values for static pressure and heat rise.
- ✔ Supply and return plenums should be mechanically fastened with screws and sealed to air handler with mastic and fabric mesh tape to form an essentially airtight connection on all sides of these important joints.
- ✔ Measure draft and test for CO. *See section 3.1.*
- ✔ All ducts should be sealed. *See section 5.1.*
- ✔ Heat rise (supply temperature minus return temperature) must be within manufacturer's specifications.
- ✔ High limit should stop fuel flow at 250° F or less. Furnace must not cycle on high limit.



80+ gas furnace: An 80+ furnace has a restrictive heat exchanger, a draft fan, and has no draft diverter or standing pilot.
90+ gas furnace: A 90+ furnace has a condensing heat exchanger and a stronger draft fan for pulling combustion gases through its more restrictive heat exchange system and establishing a strong positive draft.

- ✔ Fan control should be adjusted to activate fan at 130° to 140° F and deactivate it at 95° to 105°F, using a thermometer. Slightly higher settings are acceptable if these recommended settings cause a comfort complaint.



Static pressure and temperature rise: Testing static pressure and temperature rise across the new furnace should verify that the duct system isn't restricted. The correct airflow, specified by the manufacturer, is necessary for high efficiency.

- ✔ Static pressure, measured in both supply and return plenums should be within manufacturer's specifications.
- ✔ Blower should not be set to operate continuously.
- ✔ Seal holes through the jacket of the air handler with mastic or foil tape.
- ✔ Filters should be held firmly in place and provide complete coverage of blower intake or return register. Filters should be easy to replace.

The new furnace should have an Annual Fuel Utilization Efficiency (AFUE) of at least 80% and be equipped with a draft-assisting fan, electronic ignition, and no draft diverter.

- ✔ Check clearances of heating unit and its vent connector to nearby combustibles, according to the International Fuel Gas Code (IFGC). *See section 3.2.*
- ✔ Clock gas meter to insure correct gas input. *See section 2.1.*
- ✔ If necessary, measure gas pressure, and increase or decrease gas pressure to obtain proper gas input.

- ✔ Test gas water heater to insure that it vents properly after installation of a sealed-combustion, 90+ AFUE furnace. Install a chimney liner if necessary.
- ✔ Set thermostat's heat anticipator to the amperage measured in the control circuit, or follow thermostat manufacturer's instructions for adjusting cycle length.
- ✔ Follow manufacturer's venting instructions along with the IFGC to establish a proper venting system.
- ✔ Ensure proper sediment trap on gas line.

Table 3.4.2: Combustion Standards for Gas-Burning Furnaces

Gas Combustion Performance Indicator	80+ Furnace	90+ Furnace
Oxygen (% O_2)	4–9%	4–9%
Stack temperature (°F)	325°–450°	90°–120°
Carbon monoxide (CO) parts per million (ppm)	≤ 100	≤ 100
Steady-state efficiency (SSE) (%)	80–82%	92–97%
Gas pressure (inches water column or IWC)	3.2–3.9	3.2–3.9
Supply temperature (°F)	120–140°	95–140°

Equipment Sizing and Selection

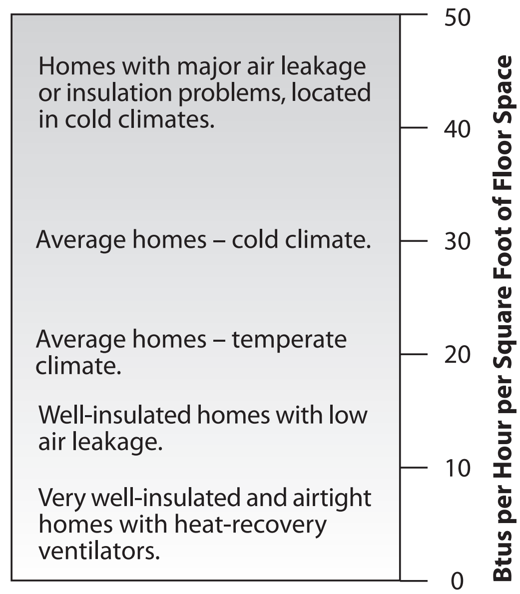
Equipment selection should be based on calculated heating and cooling loads and calculated duct sizes. Since hand calculations are complicated and tedious, progressive contractors use computer software for these design calculations.

Air handlers with their heating and cooling equipment tend to be significantly oversized. One reason is that HVAC contractors don't have adequate information or confidence about the building where they are installing the system. For example, is the natural air-leakage rate 0.1 or 1 air changes per hour? Without a blower door test, how is the HVAC contractor to know?

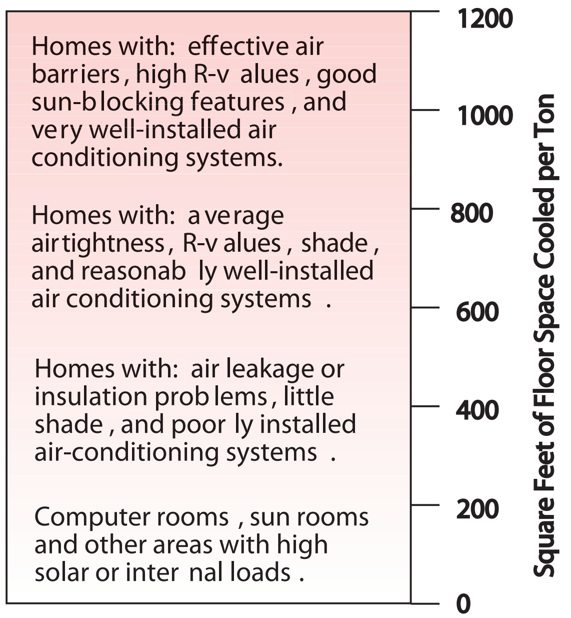
Another reason for oversizing the heating and cooling equipment are unnecessary safety factors, applied to the cooling or heating output suggested by sizing calculations. The Manual J computer software contains a safety factor of around 25%. If the contractor adds another 25% safety factor that makes 50% to 60% oversizing. If the wholesaler suggests bumping the output up another notch, the output can end up double or more what the home actually requires during outdoor design conditions.

Unfortunately, these safety factors may actually be needed to counteract the following installation problems, which sap the air handler's heating and cooling capacity.

1. Duct air leakage
2. Inadequate airflow
3. Incorrect refrigerant charge



Existing homes and their heating loads: The characteristics of the building shell and climate determine how many Btus/hour of heat are needed per square foot of floor space at design winter conditions.



Existing homes and their cooling loads: The characteristics of the building shell and climate, along with the quality of air-conditioner installation, determine how many square feet of floor space can be cooled with each ton of air conditioner capacity.

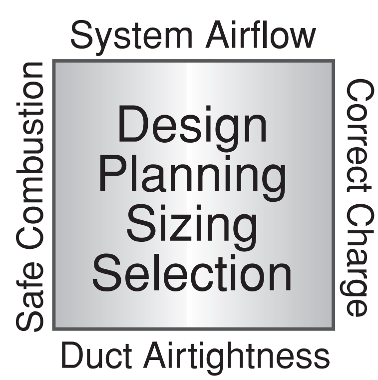
Preventing these installation problems eliminates the need for compensatory oversizing. Better planning and cooperation between general contractor and HVAC contractor can allow the HVAC contractor more space and time to provide a quality installation. And, a better building shell with a high-quality insulation package and an effective air barrier can allow HVAC contractor to install the minimum size air handler with minimum heating and cooling capacity, which provides the following benefits, compared to current typical design and installation practices.

1. Smaller ducts occupy less space and are less likely to be deformed when installed in tight building cavities.
2. Prescribed lower airflow is easier to achieve.
3. Greater operating efficiency and lower operating costs.
4. More predictable and less troublesome operation.
5. Longer equipment life span and lower maintenance cost.
6. Lower initial equipment and duct costs.
7. Better comfort and quieter operation.

Systems with two-stage compressors and two-stage gas furnaces can aide in achieving some of these goals when the HVAC contractor can't affect the home's design and construction. The first stage of heating or cooling is a far better match for most conditions than the unit's maximum output.

The best homes being built today function as integrated systems. The building shell minimizes heat loss in winter and heat gain in summer, and such a home requires a small heating and cooling system. Much of the year, neither heating nor cooling is needed. Since the shell is airtight, mechanical ventilation systems are included in these integrated homes.

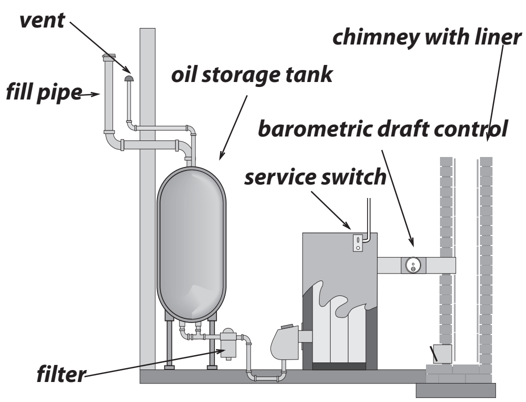
Customer comfort and satisfaction with these homes are very high. Even some home retrofitters are achieving a similar high standard for the building shell and HVAC. Considering the improvements in comfort, operating costs, health, and safety that are possible from this higher standard, the effort and initial expense is an excellent investment indeed.



OIL-FIRED HEATING STANDARDS

The overall goal of the system replacement is to provide an oil-fired heating system in virtually new condition, even though components like the oil tank, chimney, piping, or ducts may remain. Any maintenance or repair on these remaining components should be considered part of the job. Any design flaws related to the original system should be diagnosed and corrected during the heating-system replacement.

- ✔ Examine existing chimney and vent connector for suitability as venting for new appliance. The vent connector may need to be re-sized and the chimney may need to be re-lined.



Oil heating system: Components of an oil heating system may need repair and cleaning during replacement of the furnace or boiler.

- ✔ Check clearances of heating unit and its vent connector to nearby combustibles, by referring to NFPA 31.
- ✔ Check for the presence of a control that will interrupt power to the burner in the event of a fire.
- ✔ Test oil pressure to verify compliance with manufacturer's specifications.
- ✔ Test transformer voltage to verify compliance with manufacturer's specifications.
- ✔ Test control circuit amperage, and adjust thermostat heat anticipator to match.
- ✔ Adjust oxygen, flue-gas temperature, and smoke number to match manufacturer's specifications.
- ✔ Inspect oil tank and remove deposits at bottom of tank as part of new installation.
- ✔ Install new fuel filter and purge fuel lines as part of new installation.
- ✔ Bring tank and oil lines into compliance with NFPA 31.
- ✔ Check for emergency shut-off, installed in the living space.

Table 3.4.3: Min. Combustion Standards – Oil-Burning Appliances

Oil Combustion Performance Indicator	Non-Flame Retention	Flame Retention
Oxygen (% O_2)	4–9%	4–7%
Stack temperature (°F)	325°–600°	300°–500°
Carbon monoxide (CO) parts per million (ppm)	≤ 100 ppm	≤ 100 ppm
Steady-state efficiency (SSE) (%)	≥ 75%	≥ 80%
Smoke number (1–9)	≤ 2	≤ 1
Excess air (%)	≤ 100%	≤ 25%
Oil pressure pounds per square inch (psi)	≥ 100 psi	≥ 100-150 psi (pmi)*
Over-fire draft (IWC negative)	5 Pa. or .02 IWC	5 Pa. or .02 IWC
Flue draft (IWC negative)	10–25 Pa. or 0.04–0.1IWC	10–25 Pa. or 0.04–0.1IWC

* pmi = per manufacturer's specifications

3.5 ELECTRIC HEATING SYSTEMS

Electricity is a cleaner, more convenient form of energy than gas or other fuels, but it is considerably more expensive. Electric heaters are usually 100% efficient at converting the electricity to heat in the room where they are located. However, coal- or oil-generated electricity converts only about 30% of the fuel's potential energy to electricity, resulting in low system-wide efficiency and high cost.

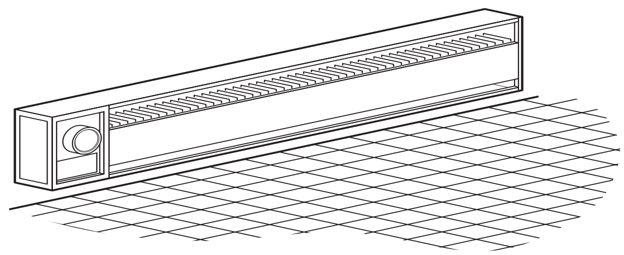
ELECTRIC BASEBOARD HEAT

Electric baseboard heaters are zonal heaters controlled by thermostats within the zone they heat. Baseboard heaters contain electric resistance heating elements encased in metal pipes. These pipes extend the length of the unit and are surrounded by aluminum fins to aid heat transfer. As air within the heater is heated, it rises into the room. This draws cooler air into the bottom of the heater.

- ✔ Make sure that the baseboard heater sits at least an inch above the floor to facilitate good air convection.
- ✔ Clean fins and remove dust and debris from around and under the baseboard heaters as often as necessary.
- ✔ Avoid putting furniture directly against the heaters. To heat properly, there must be space for air convection.

There are two kinds of built-in electric baseboard heaters: strip-heat and liquid-filled. Strip-heat units are less expensive than liquid-filled, but they don't heat as well. Strip-heat units release heat in short bursts, as the temperature of the heating elements rises to about 350°F. Liquid-filled baseboard heaters release heat more evenly over longer time periods, as the element temperature rises only to about 180°F.

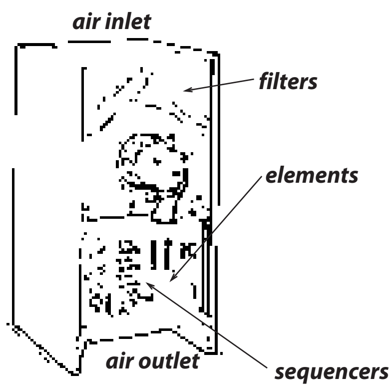
The line-voltage thermostats used with baseboard heaters sometimes do not provide good comfort. This is because they allow the temperature in the room to vary widely. Newer, more accurate thermostats are available. Automatic setback thermostats for electric baseboard heat employ timers or a resident-activated button that raises the temperature for a time and then automatically returns to setback.



Electric baseboard: Electric baseboard is more efficient than an electric furnace and sometimes even outperforms a central heat pump because it is easily zone-able. The energy bill is determined by the habits of the occupants and the energy efficiency of the building.

ELECTRIC FURNACES

An electric furnace heats air moved by its fan over several electric-resistance heating elements. Electric furnaces have three to six elements—3.5 to 7 kW each—that work like the elements in a toaster. The 24-volt thermostat circuit energizes devices called sequencers that bring the 240 volt heating elements on in stages when the thermostat calls for heat. The variable speed fan switches to a higher speed as more elements engage to keep the air temperature stable.



Electric furnace: A squirrel-cage blower blows air over 3 to 6 electric resistance coils and down into the plenum below the floor.

Electric furnaces can be a problem for utility companies if they are using more 5-kW heating elements than are necessary to heat the home—the utility has a higher peak demand than it would if only the minimum number of elements were used. During mild weather, a couple elements are needed and in severe weather they might all be needed.

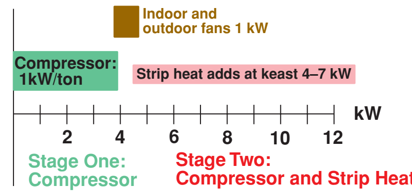
A standard heating thermostat, combined with an outdoor thermostat, can be used to stage heating elements for different weather. This is not an energy-saving measure but a power-saving measure. Since staging elements benefit the utility company, they may be willing to pay for the savings to the utility power system.

Perform these steps to service electric furnaces.

- ✔ Check and clean thermostat.
- ✔ Clean and lubricate blower if appropriate.
- ✔ Clean or replace all filters.
- ✔ Vacuum and clean housing around electric elements, if dirty.
- ✔ Clean fins on electric-baseboard systems, if applicable.
- ✔ Take extra care in duct sealing and duct airflow improvements for electric furnaces because of the high cost of electricity. *See section 5.1.*
- ✔ Verify that safety limits, heat rise, and static pressure conform to manufacturer's specifications.

Heat Pump Systems

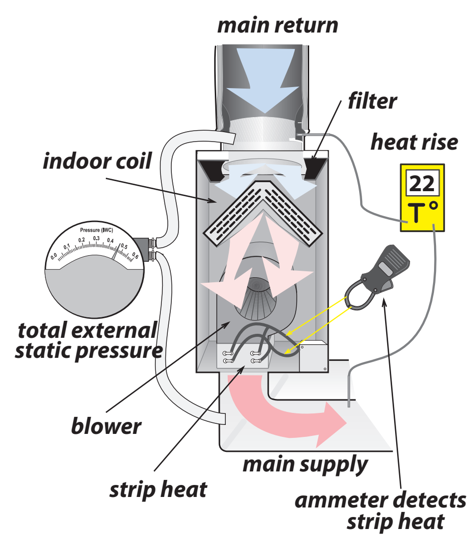
Like air conditioners, air-source heat pumps are available as centralized units with ducts or as room units. Heat pumps are 1.5 to 3 times more efficient than electric furnaces. Heat pumps can provide competitive comfort and value with combustion furnaces but they must be ducted and installed with great care and planning. Heat pumps move heat with refrigeration rather than converting it from the chemical energy of a fuel.



Is strip heat activated? Using an ammeter and the nameplate data on the heat pump, a technician can know when and if the

An air-source heat pump is almost identical to an air conditioner, except for a reversing valve that allows refrigerant to follow two different paths, one for heating and one for cooling. Heat pumps are also equipped with auxiliary electric resistance heat, called strip heat. The energy efficiency of a heat pump is largely determined by how much of the heating load can be handled by the compressor without the aid of the strip heat.

Testing central heat pumps during the summer follows the same procedures as testing central air conditioners and described in *Section 3.8.* Testing heat pumps in the winter is more difficult and some specifications follow.



Heat pump: The air handler contains a blower, indoor coil, strip heat, and often a filter. Static pressure and temperature rise are two indicators of performance.

- ✔ Look for a heat rise of around half the outdoor temperature in degrees Fahrenheit.
- ✔ Check for strip heat operation with an ammeter, using the chart shown here. Heat pumps should have two-stage thermostats designed for heat pumps. The first stage is compressor heating and the second stage is the strip heat.
- ✔ External static pressure should be 0.5 IWC (125 pascals) or less for older, fixed-speed blowers and less than 0.8 IWC (200 pascals) for variable-speed and two-speed blowers. Lower external static pressure is better. Take necessary steps to reduce external static pressure, such as enlarging branch ducts, installing additional supply and return ducts, and following other specifications starting on *See section 5.1.*
- ✔ Supply ducts should be sealed and insulated after the airflow has been verified as adequate. Return ducts should be sealed too.

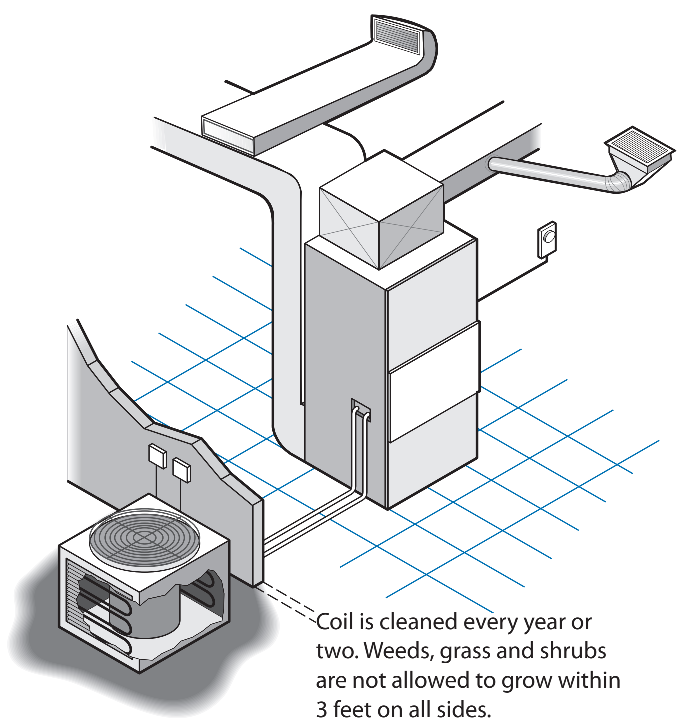
Most residential central heat pumps are split systems with evaporator and air handler indoors and condenser and compressor outdoors. The illustrations show features of an energy-efficient heat pump installation.

Individual room heat pumps are more efficient since they have the advantage of no ducts and are factory-charged with refrigerant.

Room heat pumps

Room heat pumps can provide all or part of the heating and cooling needs for small homes. These one-piece room systems (also known as terminal systems) look like a room air conditioner, but provide heating as well as cooling. They can also provide ventilation air when neither heating nor cooling are required. They mount in a window or through a framed opening in a wall.

Room heat pumps can be a good choice for replacing existing un-vented gas space heaters or obsolete central heating systems. Their fuel costs may be somewhat higher than oil or gas furnaces, though they are safer and require less maintenance than combustion appliances. Room heat pumps also gain some overall efficiency because they heat a single zone and don't have the delivery losses associated with central furnaces and ductwork. If they replace electric resistance heat, they consume only one-half



to one-third the electricity to produce the same amount of heat.

Room heat pumps have a cooling efficiency comparable to the best new window air conditioners. They operate at up to twice the efficiency of older air conditioners.

Room heat pumps draw a substantial electrical load, and may require 240-volt wiring. Provide a dedicated circuit that can support the equipment's rated electrical input. Insufficient wiring capacity can result in dangerous overheating, tripped circuit breakers, blown fuses, or motor-damaging voltage drops. In most cases a licensed electrician should confirm that the house wiring is sufficient. Don't run portable heat pumps or any other appliance with extension cords or plug adapters.

Observe the following specifications when installing room heat pumps.

- Install the unit in a central part of the home where air can circulate to other rooms. Choose a location near an electrical outlet, or where a new outlet can be installed if it's needed.
- Don't install the unit where bushes will interfere with its outdoor airflow. Heat pumps need lots of outdoor air circulation to operate at maximum efficiency.
- If you install the unit in a window, choose a double-hung or sliding window that stores out of the way. Portable units don't work well in out-swinging casement windows or up-swinging awning windows.
- If you install the unit in a framed opening in the wall, use the same guidelines you would to frame a new window or door. Provide headers, beams, or other structural supports where studs are cut, or install it in an opening under an existing window where structural support is already provided by the window framing.
- Provide solid supports underneath the unit. These can be manufactured brackets, wood-framed brackets, or brackets fabricated from metal. Fasten the unit with screws to the window jamb and/or sash.
- Seal around the exterior siding and trim to keep rain out of the wall cavity. Seal the unit to the opening with the shields provided by manufacturer or with plywood, caulking, or sheet metal.

Table 3.5.1: Installing Room Heat Pumps of Air Conditioners

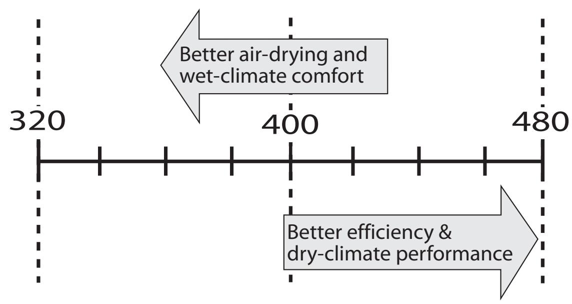
Issue	Window installation	Wall installation
Difficulty of installation	Easiest.	Wall framing required.
Access issues	Window will be inoperable, with no access for fire egress or ventilation.	None.
Air sealing	Care required to properly seal unit to window jambs.	Easy to seal permanently.
Future adaptability	Easy to remove if homeowner switches fuel or type of system.	Poor. Homeowner is left with a hole in the wall if they switch fuel or type of system.

3.6 MEASURING AND EVALUATING SYSTEM AIRFLOW

Cooling efficiency is more dependent on airflow than heating efficiency. Also, refrigerant charge and airflow are interdependent and are best checked during the cooling season.

The correct airflow for a heat pump or air conditioner is usually expressed in cubic feet per minute per ton of cooling capacity (one ton equals 12,000 Btus per hour). When the heat pump or air conditioner is operating in the cooling mode, the acceptable airflow rate is 400 cfm ±20%, according to most manufacturers.

In dry climates, you may increase performance and efficiency by increasing airflow to 480 cfm per ton if noise and comfort allow. In wet climates, the recommended airflow per ton may be somewhat less than 400 cfm per ton to facilitate dehumidification by keeping the coil cooler and air moving slower across the coil.



Airflow and climate: More airflow per ton provides better efficiency and performance for dry climates, and less airflow provides better dehumidification for wet climates.

Airflow is often measured both before duct-sealing and after because duct-sealing may change the measured airflow. Tighter ducts may be more restrictive because duct leaks provide pressure relief through additional inlet and outlet area, which is lost when they are sealed.

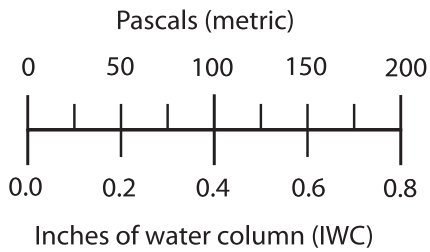
Technicians use a number of different airflow measuring techniques, depending on their equipment, training, and preferences. The type of air handler and ducts is also a factor when choosing an airflow-measuring method.

The most accurate and reliable methods for measuring system airflow are the duct-blower method and the flow-plate method. Measuring return airflow with a flow hood is also a fairly accurate and reliable method if the flow hood is properly calibrated and used according to manufacturer's instructions.

There are also a couple of airflow indicators, which are measurements of static pressure and temperature change across the indoor coil. These measurements won't give an accurate measurement of airflow, but they are used to detect inadequate airflow.

Airflow and blower speed

A blower in the air handler can have as many as five speeds. The first step in measuring airflow by any of the methods described here is to make sure that the blower is operating at one of the higher speeds, normally reserved for cooling. (Heating typically uses a lower speed.) Sometimes cooling is assigned a lower blower speed by mistake, so checking which blower speed is paired with cooling is a necessary preparatory step to airflow testing. If the blower speed isn't obvious when looking at the air-handler terminal block, clamp an ammeter around the color of wire corresponding to one of the higher speeds, in order to determine which blower speed is energized while cooling. It isn't necessary to operate the compressor and condenser fan in order to measure airflow.



Pressure in two measurement systems: Technicians and engineers use both Pascals (metric) and inches of water column (American) to measure duct pressures.

Preparing to measure airflow

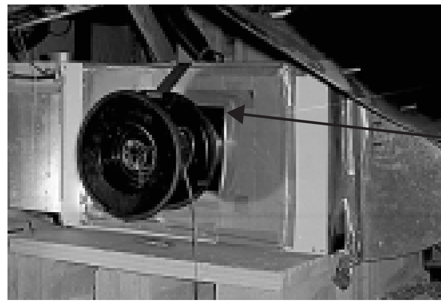
The idea behind the following preparatory steps is to solve any obvious large problems. We really don't need sophisticated test instruments to discover that filters, indoor coils, or blowers are packed with dirt or that the branch duct to the master bedroom is disconnected. Finding these problems before measuring duct airflow will speed up the commissioning process. The following steps precede airflow measurements.

1. Ask the customer about comfort problems and temperature differences in various parts of the home.
2. Based on the customers comments, look for disconnected or restricted ducts.
3. Inspect the filter(s), blower, and indoor coil for dirt. Clean them if necessary. If the indoor coil isn't easily visible, a dirty blower is a fair indicator that the coil may also be dirty.
4. From the nameplate, note the cooling capacity in tons. Tons = Btu/hour ÷ 12,000. The ideal airflow is around 400 cfm per ton.
5. Notice moisture problems like mold and mildew. Moisture sources, like a wet crawl space, can overpower air conditioners by introducing more moisture into the air than the air conditioner can remove.

DUCT-BLOWER AIRFLOW MEASUREMENT

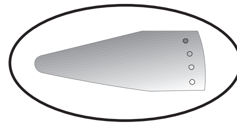
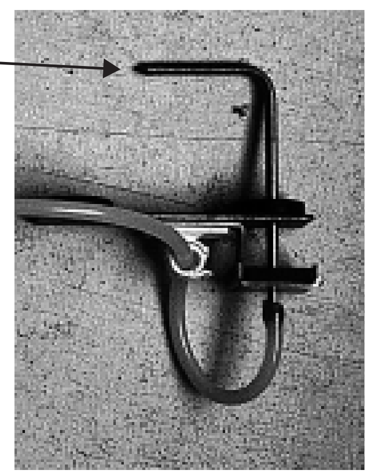
The duct blower is a fan mounted in an aerodynamic housing and equipped with a precise pressure-sampling tube. The duct blower is the most accurate airflow-measuring device currently available.

During this airflow test, all return air is routed through the duct blower where the airflow can be measured. The return air traveling through the duct blower is moved by the air handler's blower aided by the duct blower.



Main return is disconnected and the air handler is sealed.

Duct blower mounted to air handler: The best way to measure airflow with a duct blower is to connect the duct blower to the air handler and seal the main return.

Static pressure probe: Tiny holes near the tip sense static pressure from airflow perpendicular to the holes.

1. Set up a static pressure gauge to measure the duct pressure in the supply plenum, or a few feet away from the supply plenum, in a main supply. Tape the static pressure probe to hold it in place. The point of the probe should face into the oncoming airflow with the probe's static-pressure openings perpendicular to the airflow direction.
2. Make sure all supply registers and return grills are open. Leave filters installed.
3. Turn on the system and measure static pressure from the probe installed in Step 1.

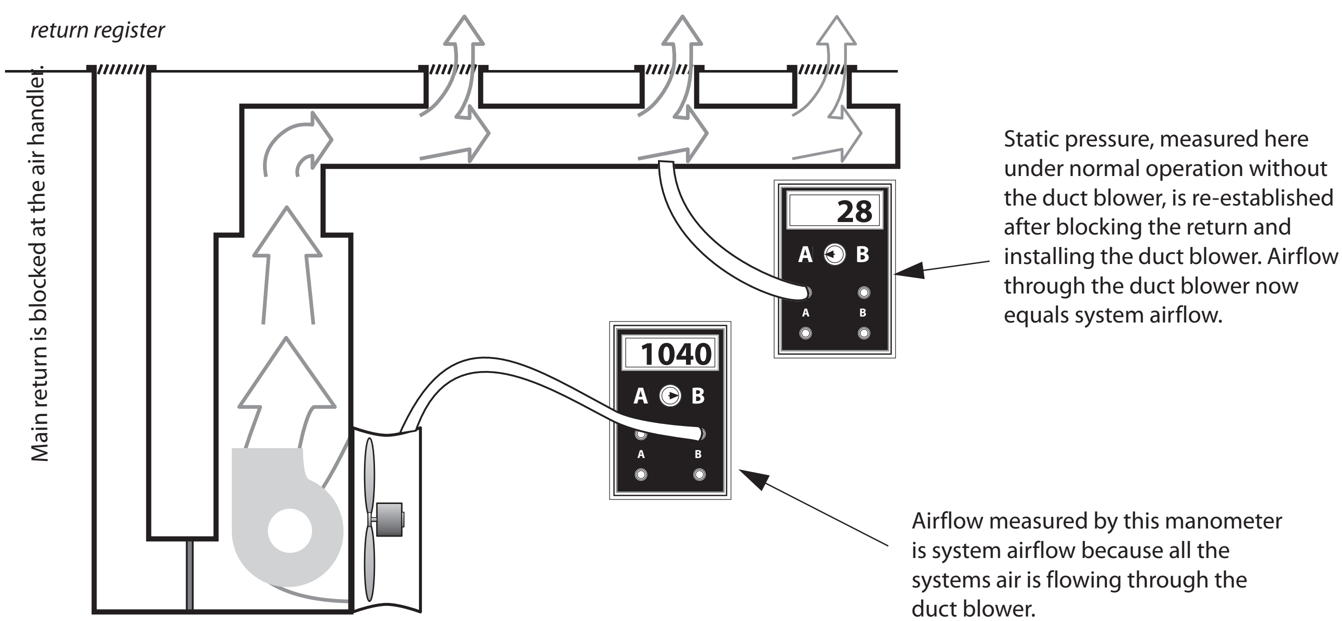
4. Shut off power to the air handler. Connect the duct blower to blow into the air handler at the blower compartment or the single return register, using one of the two options outlined below.

- **For single- or multiple-return systems:** The preferred method of connecting the duct blower is to block the return plenum's main return entry to the air handler. Filters are often installed in a good location to achieve this temporary blockage. Alternatively, you can support the main return and move it temporarily out of your way, while you seal the opening to the air handler with cardboard and tape. Then connect the duct blower to the blower compartment after removing the door.
- **Option for single-return systems:** Remove the grill at the single return register. Connect the duct blower through its flexible tube or else directly to the register, using cardboard to block off the excess area of the register. (Note: If there is significant return leakage, airflow measurement will be artificially high.)

Duct blower mounted to main return: With a single return, it's convenient to attach the duct blower to the single main return register. However, this option may result in an artificially high airflow reading.

All the return air should now come through the duct blower. If the duct blower is connected to an air handler, located outside the conditioned space, the door or access panel between the conditioned space and the air handler location must be opened. Now you are ready to measure system airflow.

1. Turn on the air-handler fan once again, making sure the air-handler fan is running at the correct speed for cooling.
2. Turn on the duct blower to blow into the air handler, increasing airflow until the manometer measuring supply-plenum static pressure reads the same as your original static-pressure measurement.



3. Measure and record the airflow through the duct blower. Refer to the duct-blower instruction book, if necessary, to insure that you know how to take the reading. The airflow reading you take directly from the digital manometer or look up in the manufacturer's table for converting pressure to flow is total system airflow in cubic feet per minute (CFM).

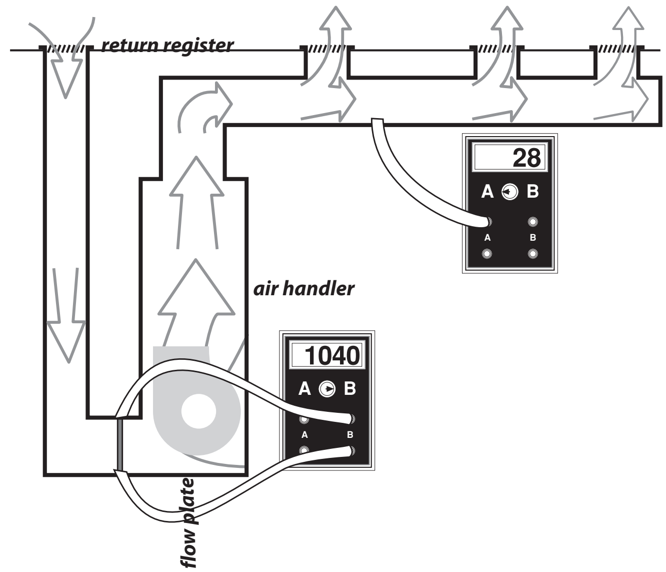
Flow-plate airflow measurement

The TrueFlow® air-handler flow meter, manufactured by The Energy Conservatory of Minneapolis, is relatively fast and easy to use. This flow meter is a plate with holes and sampling tubes that samples and averages velocity pressures and converts them into an airflow measurement.

One of two flow plates are inserted and sealed at their edges in the filter slot or bracket within the air handler. Then, the static-pressure drop across the flow plate is measured and airflow is found on printed tables supplied by the manufacturer or automatically by the digital manometer.

When used according to the manufacturer's instructions, which are summarized below, the accuracy of this method is better than the other tests described on these pages, with the exception of the duct-blower test. Refer to the manufacturer's instructions for the precise testing method. A summary follows.

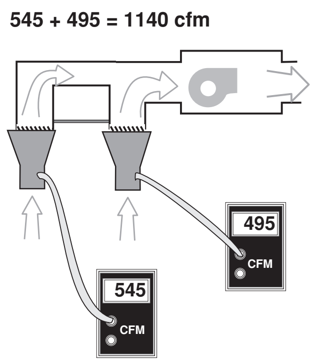
1. Measure and record the normal system operating pressure, with a standard filter in place, using a static pressure probe in the supply plenum or supply duct near the air handler.
2. Replace the existing filter with the flow plate. Seal the flow plate into the slot, according to the manufacturer's recommendations.
3. Measure and record the system's operating pressure with the flow plate in place, at the same location as when the filter was in place.
4. Measure the flow through the TrueFlow Meter using the digital manometer supplied by the manufacturer. Obtain flow from the numerical table or the digital manometer itself.
5. Calculate a correction factor from the measured operating pressures (using a correction table) and multiply by the measured flow to get the original flow rate, moving through the air handler when the first measurement was taken.



True Flow® Meter: The True Flow® flow plate installs in a filter slot and measures system airflow almost as accurately as the duct blower.

Flow hood airflow measurement

This test measures the fairly laminar airflow at return registers. Measuring supply-register airflow isn't as accurate as measuring return airflow because supply air is more turbulent and because floor supply registers close to walls don't allow the flow hood to be centered over them. The flow-hood inlet must be larger than the return grills, although 10 percent of the register may be blocked with tape to allow the flow hood to cover that reduced opening.



Measuring return air with a flow hood: This method provides an estimate of system airflow. It can significantly underestimate airflow because return duct leakage bypasses the measurement.

This test works best on systems with one to four return grills located in areas where a flow hood can cover the grills and be centered over them. Keep in mind that the return airflow will appear low if the return ducts are very leaky. A low reading may mean that the system is drawing some of its return air from a crawl space, attic, or attached garage.

1. Turn on the air handler to run at the higher fan speed, normally used for cooling.
2. Center the flow hood over the return register, covering it completely. If the register is larger than the flow hood, seal up to 10 percent of the register with tape before covering it.
3. Read and record the airflows through the return registers. Add the measured airflows of the return registers together to get the total system airflow.

Measuring total external static pressure

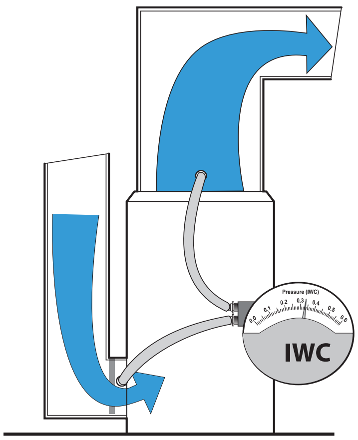
Total exterior static pressure (TESP), created by the duct system, gives a rough indicator of whether airflow is adequate. TESP is the sum of the absolute values of the supply and return static pressures. The supply and return static pressures by themselves can indicate whether the supply or return or both are restricted. The greater the TESP, the lower the airflow.

The TESP test can estimate airflow if the manufacturer's table for static pressure versus airflow is available. The ducts, registers, and a coil mounted in the ducts (if present) create the system's resistance measured by static pressure in inches of water column (IWC) or pascals. The return static is negative and the supply static is positive. The positive or negative signs are disregarded when adding supply static and return static to get TESP.

1. Attach two static pressure probes to tubes leading to the ports of the manometer. For analog manometers, attach the high-side port to the probe inserted downstream of the coil or air handler.
2. Take the readings on each side of the air handler to obtain both supply and return static pressures separately. Disregard positive or negative signs given by a digital manometer when performing addition.
3. Consult manufacturer's literature for a table, relating static pressure difference to airflow for the blower or air handler. Find airflow for the static pressure measured above.

Air handlers deliver their airflow at a TESPs ranging from 0.30 IWC (50 Pascals) and 1.0 IWC (250 Pascals) as found in the field. Manufacturers maximum recommended static pressure is usually a maximum 0.50 IWC for standard air handlers. TESPs greater than 0.50 IWC indicate the possibility of poor airflow in standard residential forced-air systems.

The popularity of pleated filters, electrostatic filters, electronic air cleaners, and high-static high-efficiency evaporator coils, prompted manufacturers to introduce premium air handlers that can deliver adequate airflow at TESP of greater than 0.50 IWC. Premium residential air handlers can provide adequate airflow with TESP up to 0.90 IWC. TESPs greater than 1.00 IWC indicate the possibility of poor airflow in these premium residential forced-air systems.



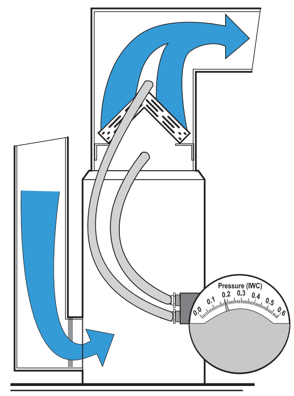
Total external static pressure (TESP): The positive and negative pressures created by the resistance of the supply and return ducts produces TESP. The measurement shown here simply adds the two static pressures without regard for their signs. As TESP increases, airflow decreases. Numbers shown here are for example only.

Table 3.6.1: Total external static pressure versus system airflow

TESP (IWC)	0.3	0.4	0.5	0.6	0.7	0.8
CFM	995	945	895	840	760	670

STATIC-PRESSURE DROP ACROSS COIL OR FILTER

Measuring static pressure drop across a coil or filter can give a fair estimate of airflow when the filter or coil is new. Manufacturers often provide a table showing airflow through the filter or coil under different static pressures. Static pressure can vary widely from point to point within the measurement area, especially when ducts take an abrupt change of direction near the air handler. Access to both sides of the coil for testing static pressure can be difficult. Drilling test holes requires care and planning to avoid damaging the indoor coil if it is located in a duct.



Static pressure drop across coil: The more static pressure applied to a new clean coil, the greater the airflow will be through it. Manufacturers often provide data for both dry and wet coils. Numbers shown here for example only.

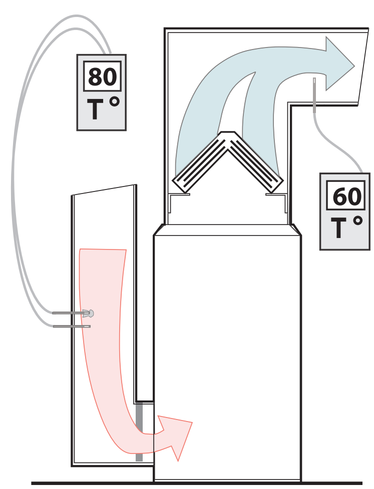
Table 3.6.1: Static-pressure drop versus airflow through coil

S.P.	.23	.27	.31	.36	.41
CFM	1000	1100	1200	1300	1400

CARRIER® TEMPERATURE-SPLIT METHOD

Carrier Corporation uses dry-bulb supply temperature as an indicator of whether airflow is adequate. This method requires measuring the return-air wet-bulb and dry-bulb temperatures. From these temperatures, the recommended dry-bulb temperature is determined from a slide rule provided by Carrier. If the measured dry-bulb temperature is lower than the listed value, the airflow is probably too low. If the temperature is higher than the listed value, the airflow is probably higher than 400 cfm per ton, which is usually no problem.

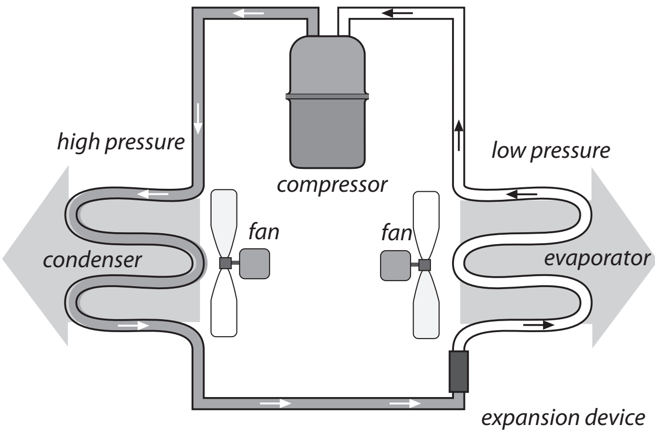
For recommendations on improving duct-system airflow, see *Section 3.6.*



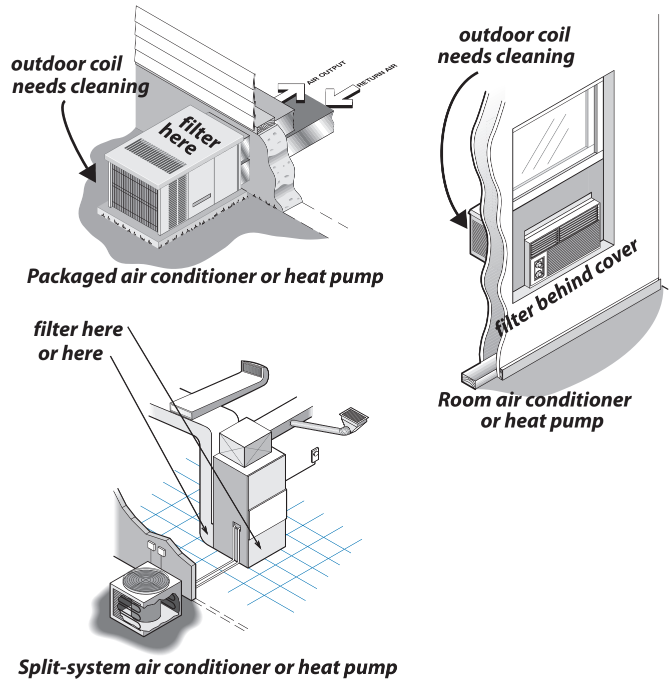
Carrier temperature-split method: First measure return wet-bulb and dry-bulb temperature. Check the chart below for the suggest supply dry-bulb temperature. Then measure the actual dry-bulb supply temperature. If the measured temperature is lower than suggested, the airflow is too low.

3.7 AIR CONDITIONING SYSTEMS

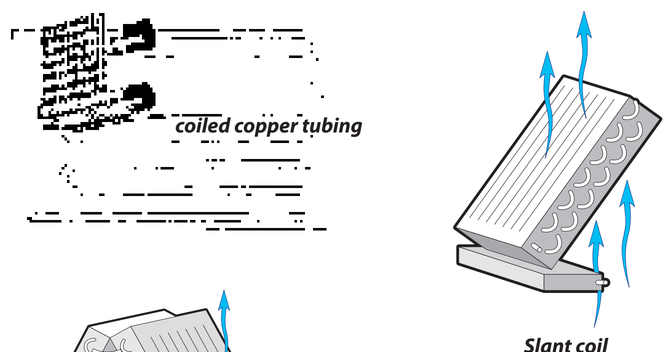
Air conditioners come in two basic types, packaged systems and split systems. Packaged air conditioners include room air conditioners and room heat pumps, along with packaged central air conditioners and heat pumps mounted on roofs and on concrete slabs outdoors. Split systems have a condenser outdoors and an air-conditioning coil, located indoors inside a furnace, heat pump, or adjoining main supply duct.

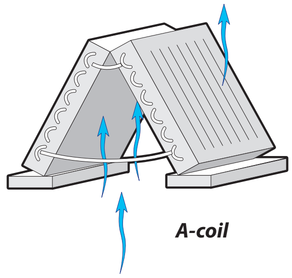


Refrigeration and air-conditioning cycle: Refrigerant evaporates in the evaporator, absorbing heat from the metal coil and the indoor air. The compressor compresses the refrigerant, and moves it to the condenser. In the condenser, the condensing refrigerant heats the condenser coil to a significantly higher temperature than the outdoor air. The outdoor air that circulates through the condenser then removes the heat that was collected from indoors.



Air conditioner types: Room air conditioners are most common type for low-income homes. All types of air conditioners need clean filters and coils to achieve acceptable efficiency.





Air-conditioning coils: Evaporator and condenser coils gather dust over time, which reduces airflow and heat transfer.

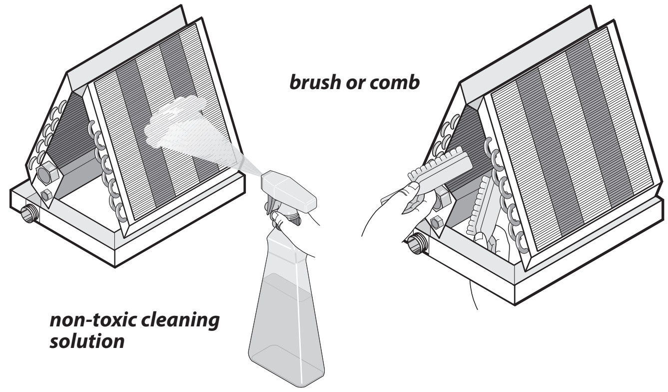
CLEANING BLOWERS AND INDOOR COILS

Every indoor coil should be protected by an air filter that fills the entire cross-sectional area of return duct leading to the blower and indoor coil. Filters are easier to change or clean compared to cleaning a blower or coil. If equipped with clean well-fitting filters, the blower and coil will remain clean for many years. However, many coils haven't had the benefit of such filters and are packed with dirt.

Dirt builds up on a coil from the side where the air enters. The heaviest deposits of lint, hair, and grease will coat that side of the indoor coil. The best strategy is to dampen this surface layer and brush the heavy dirt off before trying to wash the finer dirt out with a biodegradable indoor coil cleaner and water.

1. Shut off the main switch to the air handler.
2. Open the blower compartment and look into the blades of the blower, using a flashlight. Reach in and slide your finger along a fan blade. Have you collected a mound of dust?
3. If the blower is dirty, remove it and clean it. If you remove the motor, you can use hot water or household cleanser to remove the dirt.
4. If the blower is dirty, the indoor coil is probably also dirty. Inspect the coil visually if you have access. Create an access hatch if needed.
5. If the coil is dirty, clean it using a brush, indoor coil cleaner and water.
6. Straighten bent fins with a fin comb to prevent bent fins from reducing airflow.
7. Clean the drain pan and drain line.

The outdoor coils of air conditioning systems aren't protected by filters. They get dirty depending on how much dust is in the outdoor air. If there is little dust and pollen in an area, the outdoor coil may only need cleaning every three years or so. However, if there is a lot of pollen and dust, annual cleaning is a good practice. It is a safe assumption that all outdoor coils need cleaning. Use a biodegradable cleaner designed for cleaning outdoor coils.



Cleaning an A-coil: A-coils are found in upflow and downflow air handlers. In downflow models the dirt collects on top and on upflow units dirt collects on the bottom. Clean the coil, drain pan, and drain line.

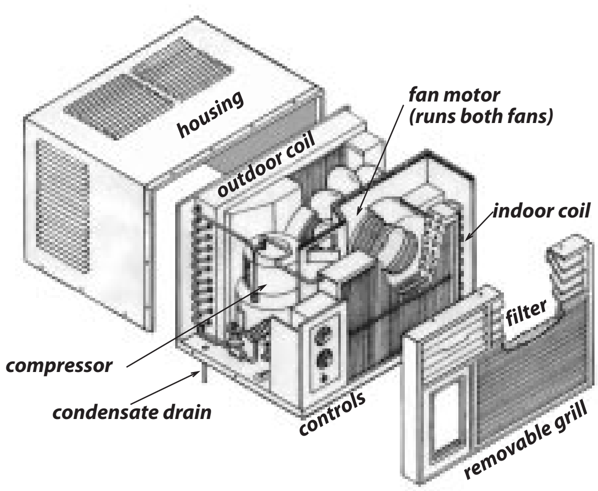
Cleaning room air conditioners

Room air conditioners have foam or fiberglass filters that lie up against the inside coil. It's good practice to carry a roll of filter material to replace worn-out or non-existent filters. Cleaning the indoor coil is easy since the heaviest dirt collects on the surface of the coil facing the inside of the home. Cleaning the outdoor coil is more difficult. Usually cleaning the outdoor coil involves removing the room air conditioner from the window and taking it to an outdoor location where you can use a garden hose. The housing of the air conditioner must be removed to clean the outdoor coil. Again, use indoor coil cleaner for the indoor coil and outdoor coil cleaner for the outdoor coil. Each is designed for a different variety of dirt and has different environmental specifications.

Observe the following steps when cleaning the indoor and outdoor coils of a room air conditioner.

1. Remove the grill and filter on the interior side of the unit.
2. Unplug and remove the air conditioner temporarily from the window or wall. With some units, the mechanical parts slide out of the housing, and with others you must remove the whole unit, housing and all.
3. Take the unit to a clean outdoor area that drains well, like a driveway or patio.

4. Cover the compressor, fan motor, and electrical components with plastic bags, held in place with rubber bands.
5. Dampen each of the coils with a light spray of water, then rake as much dirt off the coils as you can with an old hairbrush.
6. Spray indoor coil cleaner into the indoor coil and outdoor coil cleaner into the outdoor coil, and let the cleaner set for a minute or two.
7. Rinse the cleaner and dirt out of the coils with a gentle spray from a hose.
8. Repeat the process again until the water draining from the coils is clean.
9. Straighten bent fins with a fin comb to prevent bent fins from reducing airflow.



Cleaning room air conditioners: Room-air-conditioner performance deteriorates as it accumulates dirt. The unit will eventually fail to cool the room or break down unless cleaned.

3.8 Evaluating Refrigerant Charge

The performance and efficiency of residential and light-commercial air conditioners and heat pumps is very dependent upon having the correct amount of refrigerant in the system. This section describes accepted procedures for measuring and adjusting refrigerant charge in residential and light-commercial air conditioners and heat pumps.

The testing procedure for different air conditioners and heat pumps depends on the type of expansion valve the unit has. Units with fixed-orifice expansion devices require superheat testing. Units with TXVs require subcooling testing. All testing and subsequent addition or removal of refrigerant should be done by qualified and EPA-licensed refrigeration technicians.

Preparations for Charge Testing

Refrigerant-charge testing and adjustment should be done after airflow measurement and improvement and after duct testing and sealing. The logic behind this sequence is that airflow should be adequate before duct sealing is done in case you have to add or enlarge ducts. Manufacturers recommend that adequate airflow be verified before charge is checked and adjusted.

With existing condenser units, it's an excellent idea to clean the condenser coil before testing and adjusting refrigerant charge. After cleaning the coil with outdoor coil cleaner, let the coil dry thoroughly. Otherwise suction and head pressures will read abnormally low.

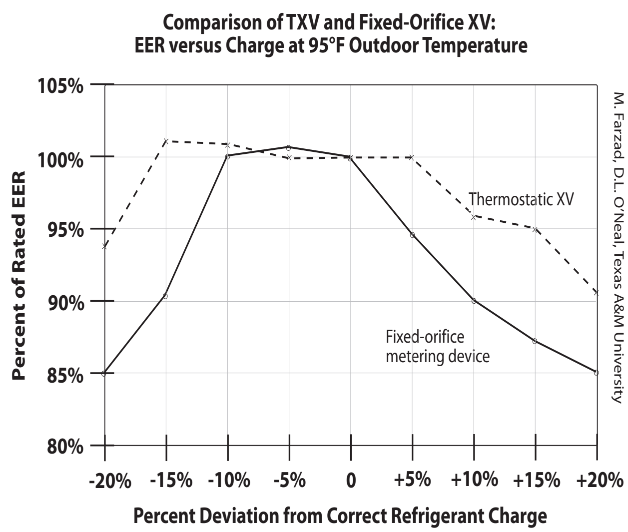
Required equipment

For withdrawing refrigerant, use a U.S. Department of Transportation (D.O.T.) recovery cylinder. You'll usually be adding refrigerant from a R-22 or R-410A cylinder, however you can put refrigerant back into the same unit from the recovery cylinder after evacuating the system.

Required equipment includes a refrigeration gauge set and a digital thermometer. The digital thermometer should have a cloth covering for the tip of one of its thermocouples, which is wetted to measure wet-bulb temperature of air entering the evaporator. A sling psychrometer can also be used to measure wet-bulb temperature of air entering the evaporator.

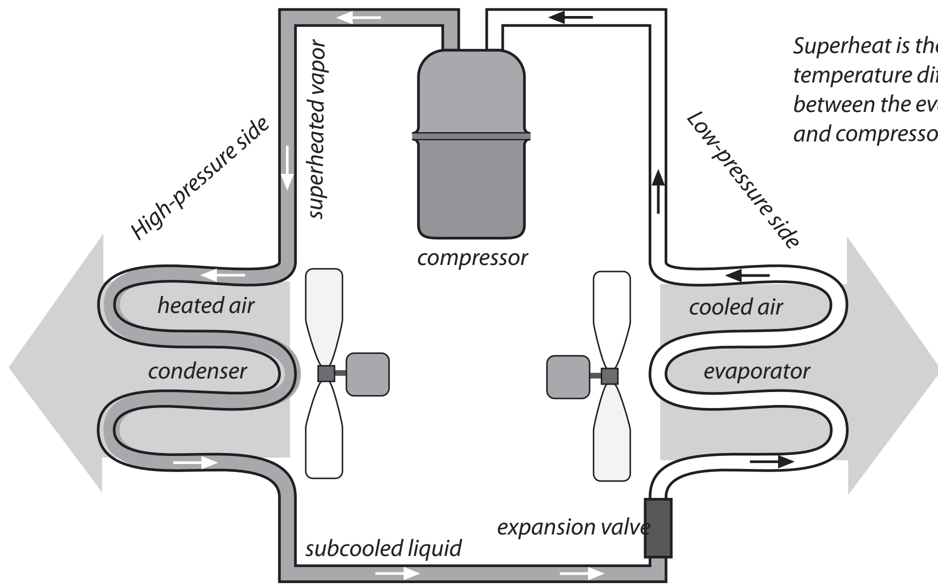
Evaporator Superheat Test

Adjusting the refrigerant charge to produce the recommended superheat temperature, based on current indoor and outdoor temperatures optimizes system performance and efficiency. Superheat is an good indicator of correct charging for air conditioners and heat pumps with capillary-tube or fixed-orifice expansion devices, operating in the cooling mode.

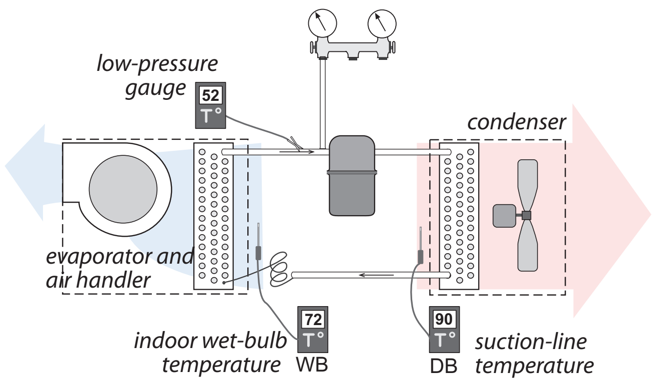


Energy Efficiency Ratio (EER) degrades with incorrect charge: Thermostatic expansion valves compensate a little for charge that is too high or low. Fixed-orifice expansion devices are more severely affected by incorrect charge.

Use this test only for fixed orifice or capillary-tube systems and not for thermostatic expansion value (TVX) systems. This test should only be done when the outdoor temperature is at least 60°F.



1. Before checking charge, test and verify adequate airflow, using procedures in *Section 3.6.*
2. Measure the dry bulb temperature of the air entering the outdoor coil.
3. Measure the wet bulb temperature of the return air at the air handler.
4. Determine the recommended superheat temperature from a superheat table.
5. Measure the compressor-suction pressure at the suction-service valve. Add 2 pounds per square inch of gauge pressure (psig) for line losses between the evaporator and compressor. Then convert this adjusted pressure to a boiling-point temperature using temperature-pressure tables.
6. Measure the suction-line temperature at the suction service valve by attaching a thermocouple there, taped and insulated to the piping.
7. Subtract the boiling-point temperature determined in (4) from the measured temperature in (5). This is the actual superheat temperature.
8. If the actual superheat is greater than the recommended superheat obtained from the table by more than 5°F, add 2-4 ounces of refrigerant, and wait at least ten minutes before repeating this superheat procedure.
9. If the actual superheat is less than the ideal by more than 5°F, remove 2-4 ounces refrigerant, and wait at least ten minutes before measuring superheat again. Refrigerant must be removed into a Department-of-Transportation-approved (DOT-approved) recovery cylinder, either empty or containing the same refrigerant as the system.



Superheat test: Superheat is the heat added to the evaporating vapor to ensure that no liquid enters the compressor. For a fixed-orifice system this value varies with outdoor temperature and indoor temperature and humidity.

Limitations of the Superheat Test

First, superheat won't be accurate unless airflow is around 400 cfm per ton, so airflow should be measured and improved, if inadequate. Sometimes you can't charge by superheat because of either low or high outdoor temperature. Superheat disappears at high outdoor temperatures, and charge-checking at these temperatures is not recommended. As outdoor temperature rises, system pressures rise, and refrigerant flow rate through the fixed orifice increases until flooding may occur. Therefore, some superheat is desirable, even at high outdoor temperatures to protect the compressor from liquid refrigerant. Providing 1 to 5°F of superheat—even at high outdoor temperatures where superheat values aren't listed—would create a slight undercharge, which would protect the compressor while slightly improving hot-weather performance.

Subcooling Test to Ensure Proper Charge

Follow manufacturer's instructions for the subcooling test, if available. This test is only to be used for thermal expansion valve (TXV) systems when the outdoor temperature is at least 60°F. The air conditioner or heat pump should be running in the cooling mode for 10 minutes prior to the test.

1. Measure the liquid pressure at the liquid service valve. Convert this pressure to the condenser saturation temperature, using temperature-pressure tables for the system's refrigerant.
2. Measure the temperature of the liquid refrigerant leaving the condenser.
3. Subtract the liquid-refrigerant temperature measured in (2) from the condensing temperature determined in (1). This is the subcooling.
4. Find the correct subcooling from the permanent sticker inside the condenser unit, from manufacturer's literature, or from a manufacturer's slide rule. Add refrigerant if the measured subcooling temperature is 3°F or more below the recommendation. Withdraw refrigerant if the subcooling temperature is 3°F or more greater than recommended. Refrigerant must be removed into an empty DOT-approved recovery cylinder or one containing the same refrigerant as the system.

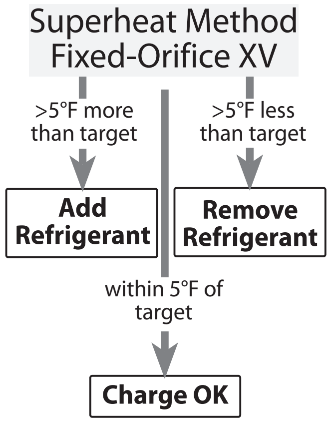
Allow the system to run for 10 minutes to adjust to the new operating conditions. Repeat the subcooling procedure, until the measured subcooling temperature matches manufacturer's recommendations or is between 10° and 15°F.

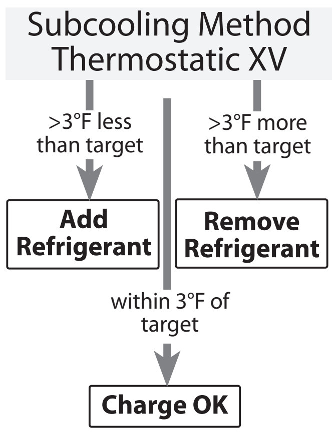
Table 3.8.1: Ideal Superheat Values for Different Indoor and Outdoor Conditions

Measured Return-Air Wet Bulb	Measured Outdoor Condenser Entering Dry-Bulb Temperature												
	55	60	65	70	75	80	85	90	95	100	105	110	115
76	45	43	41	39	37	35	33	31	29	27	26	25	23
74	42	40	38	36	34	31	30	27	25	23	22	20	18
72	40	38	36	33	30	28	26	24	22	20	17	15	14
70	37	35	33	30	28	25	22	20	18	15	13	11	8
68	35	33	30	27	24	21	19	16	14	12	9	6	-
66	32	30	27	24	21	18	15	13	10	8	5	-	-
64	29	27	24	21	18	15	11	9	6	-	-	-	-
62	26	24	21	19	15	12	8	5	-	-	-	-	-
60	23	21	19	16	12	8	-	-	-	-	-	-	-
58	20	18	16	13	9	5	-	-	-	-	-	-	-
56	17	15	13	10	6	-	-	-	-	-	-	-	-
54	14	12	10	7	-	-	-	-	-	-	-	-	-
52	12	10	6	-	-	-	-	-	-	-	-	-	-
50	9	7	-	-	-	-	-	-	-	-	-	-	-

Interpreting Subcooling

The thermostatic expansion valve is the best available metering device because it varies the orifice size to meet changing indoor and outdoor conditions. It compensates for low airflow and incorrect charge better than fixed orifice expansion valves. With luck, the technician will find a recommendation for subcooling in the manufacturer's literature or on the nameplate or sticker somewhere in the outdoor unit. A subcooling temperature between 10° and 15°F is common for a properly functioning residential air conditioner, but it is better to use manufacturer's specifications for subcooling if they are available.

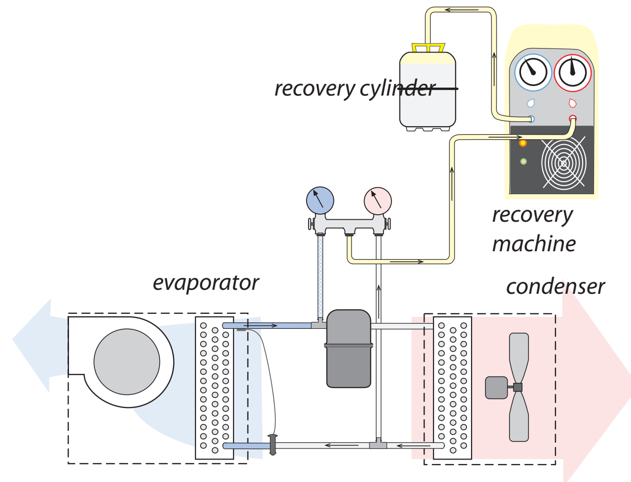




WEIGH-IN TEST FOR PROPER REFRIGERANT CHARGE

This is the preferred method of achieving the correct charge. Weigh in refrigerant whenever you are charging:

- New installations,
- Systems where the refrigerant has leaked out,
- To correct refrigerant charge if found to be incorrect after checking superheat or subcooling, or
- To remove existing refrigerant in an EPA-approved manner and recharge the system by weighing in the correct amount of refrigerant whenever superheat or subcooling tests can't be employed.



Refrigerant recovery. Most of the refrigerant will flow from the system to a recovery cylinder as a liquid, while being filtered by the recovery machine. The recovery machine can recover the most of the remaining refrigerant as a vapor by pulling a vacuum of 10 inches of mercury.

Follow these procedures to evacuate the existing charge and weigh in the correct one.

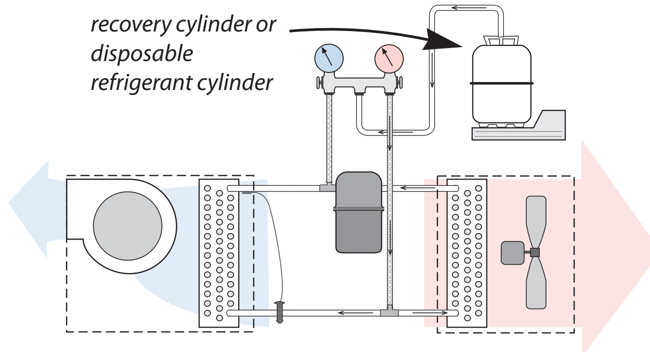
1. Follow the recovery machine's operating instructions for connecting hoses.
2. Remove the refrigerant with the recovery machine. The recovery machine should pull a vacuum of at least 10 inches of mercury. Recover the refrigerant into a DOT-approved cylinder, noting the weight of refrigerant recovered and recycled.
3. Evacuate the system to 500 microns to remove moisture and impurities, using a vacuum pump.
4. Determine the correct charge by reading it from the nameplate. From manufacturer's literature or by contacting a manufacturer's representative, determine the length of lineset that the nameplate charge assumes.
5. Accurately measure the unit's installed lineset length. Depending on whether the existing lineset is longer or shorter than the manufacturer's assumed lineset length, add or subtract ounces of refrigerant, based on the manufacturer's specifications of refrigerant ounces per foot of suction and liquid line.

6. Connect the EPA-approved recovery cylinder or disposable cylinder to the gauge manifold. Place the cylinder on an electronic scale and zero the scale. During charging, be very careful not to bump or otherwise disturb the scale or cylinder. The scale could reset itself, forcing you to evacuate and start all over.
7. To prepare for liquid charging, connect the common port of the gauge manifold to the liquid valve of the recovery cylinder. If using a disposable cylinder, turn the cylinder upside down after connecting the common port to the cylinder valve.
8. With the compressor off, open the cylinder's valve and suction service valve, and let the liquid refrigerant flow in.

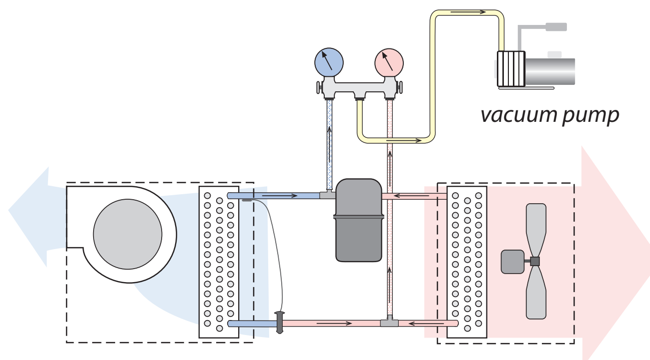
Purging refrigerant for a gauge hose

When you connect your high-pressure gauge to the high-pressure liquid service valve, the hose fills with liquid refrigerant. Rather than releasing this refrigerant into the atmosphere or carrying it around to contaminate another system, run it back into the low-pressure suction service valve. Modern hoses hold refrigerant under pressure when they are disconnected, so disconnect the high-pressure hose. Open the common chamber of the gauge set to the suction service valve. Then open the common chamber to the high-pressure hose, slowly letting the liquid refrigerant hiss through the chamber, vaporizing before reaching the low-pressure service valve or nearby compressor.

9. If liquid stops flowing before the correct charge has entered, reconfigure the gauge manifold and cylinder to charge with vapor through the suction service valve.
10. With the compressor running, add the remaining refrigerant as a vapor. Before opening path between the cylinder and the system, check the low-pressure gauge to make sure the cylinder pressure is higher than the system's suction pressure.
11. Weigh in the remainder of the charge.
12. Check performance after 10 minutes of operation using superheat test or subcooling test.



Liquid charging: Most of the captured refrigerant should flow into the evacuated system as a liquid through the liquid service valve.



Vacuum-pump evacuation: The last remains of the system's refrigerant are vented into the atmosphere along with air and moisture, leaving the system clean and ready for charging.

Limitations of the Weigh-In Method

Ideally, the service technician will have the manufacturer's literature, which specifies the lineset length, assumed by the manufacturer, and the amount of refrigerant required for each foot of suction and liquid line. You may also need to know the weight of refrigerant contained in the indoor coil. The weigh-in method can't be performed accurately without this information. Without accurately measuring the lineset length, the weigh-in method can't be performed accurately either. Sometimes, the difficulty of obtaining the manufacturer's specifications makes the weigh-in method a poor choice because just the difference between the manufacturer's choices of linesets (15, 20, and 25 feet) can result in a charge no more accurate than ±5-to-15 ounces, which is unacceptable.

3.9 HYDRONIC AND STEAM SYSTEMS

The following standards refer to hot-water and steam systems commonly found in single-family homes. Hot-water and steam systems found in multifamily buildings are generally more complex and should be tested and evaluated by professionals experienced in their operation.

BOILER EFFICIENCY AND MAINTENANCE

Boilers can maintain good performance and efficiency for many years if they are regularly maintained and tuned-up. Boiler performance and efficiency improve after effective maintenance and tune-up procedures. There are more ways for performance and efficiency to deteriorate in boilers compared to furnaces. Specifically these are:

- Corrosion, scaling, and dirt on the water side of the heat exchanger.
- Corrosion, dust, and dirt on the fire side of the heat exchanger.
- Excess air during combustion from air leaks and incorrect fuel-air mixture.
- Off-cycle air circulation through the firebox and heat exchanger, removing heat from stored water.

Consider the following maintenance and efficiency improvements for both hot-water and steam boilers.

✔ Check for leaks on the boiler, around its fittings, or on any of the distribution piping connected to the boiler.

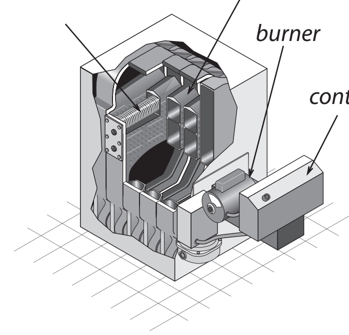
✔ Clean fire side of heat exchanger of noticeable dirt.

✔ Check doors and cleanout covers for air leakage. Replace gaskets or replace warped doors or warped cleanout covers.

✔ Drain water from the boiler drain until the water flows clean.

HOT-WATER SPACE-HEATING

Hot-water heating is generally a little more efficient than forced-air heating and considerably more efficient than steam heating. The most significant energy wasters in hot-water systems are poor steady-state efficiency, off-cycle flue losses robbing heat from stored water, and boilers operating at too high a water temperature.



Cast-iron sectional boilers: The most common boiler type for residential applications.

How to recognize a hot-water boiler
Look for a pressure tank, located somewhere above the boiler. This cylindrical tank provides an air cushion to allow the system's water to expand and contract – as it is heated and cooled – so it doesn't discharge through the relief valve

Consider the following safety checks and improvements.

✔ Confirm the existence of a 30-psi-rated pressure-relief valve. Replace a malfunctioning valve or add one if none exists. Note signs of leakage or discharges, and find out why the relief valve is discharging.

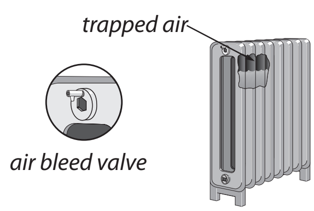
✔ Make sure that the pressure tank isn't waterlogged or sized too small for the system. This could cause the pressure-relief valve to discharge. Test pressure tank for its rated air pressure—often 15 psi.

✔ If rust is observed in venting, verify that return water temperature is above 130° F for gas and above 150° F for oil, to prevent acidic condensation.

- ✔ High-limit control should deactivate burner at 180° F or less.
- ✔ Lubricate circulator pump(s) if necessary.

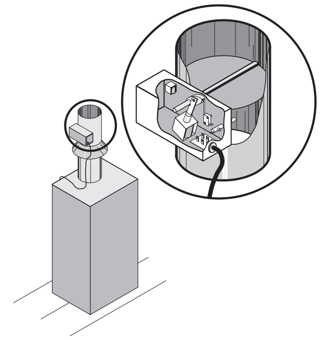
Consider the following efficiency improvements.

- ✔ Repair water leaks in the system.
- ✔ Boiler should not have low-limit control for maintaining a minimum boiler-water temperature, unless the boiler is heating domestic water in addition to space heating.
- ✔ Bleed air from radiators and piping through air vents on piping or radiators. Most systems have an automatic fill valve. If there is a manual fill valve for refilling system with water, it should be open to push water in and air out, during air purging.



Purging air: Trapped air collects at the hot-water system's highest parts. Bleeding air from radiators fills the radiator and gives it more heating surface area.

- ✔ Consider installing a two-stage thermostat or timer control to increase circulator on-time compared to burner on-time.
- ✔ Consider installing outdoor reset controllers on larger boilers to regulate water temperature, depending on outdoor temperature.
- ✔ After control improvements like two-stage thermostats or reset controllers, verify that return water temperature is high enough to prevent condensation and corrosion in the chimney as noted previously.
- ✔ Vacuum and clean fins of fin-tube convectors if you notice dust and dirt there.
- ✔ Insulate all supply piping, passing through unheated areas, with foam pipe insulation, at least one-inch thick, rated for temperatures up to 200° F.



Vent dampers: Electric vent dampers close the chimney when the burner isn't firing, preventing circulating air from carrying the boiler's stored heat up the chimney.

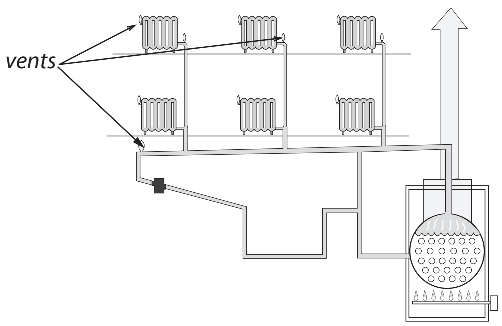
- ✔ Consider installing electric vent dampers on atmospheric gas- and oil-fired high-mass boilers.

STEAM HEATING

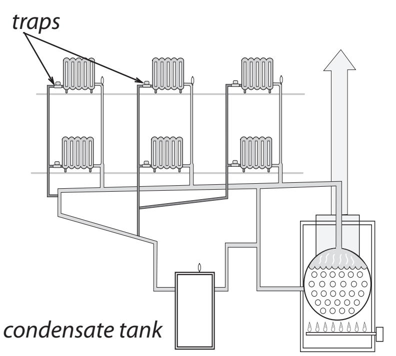
Steam heating is less efficient than hot-water heating because higher temperature heating systems are less efficient than lower temperature ones. A steam boiler heats water to its boiling point before making steam or accomplishing any space heating. Steam boilers are also more hazardous because of the steam pressure. For these reasons heating-system replacement with a hot-water or forced-air system should be considered, depending on the boiler's operating efficiency after a tune-up.

How to recognize a steam boiler
Look for the sight glass that shows the water level in the heat exchanger. The sight glass is usually attached to a float valve that controls the flow of make-up water into the boiler.

If the steam-heating system must remain, operate it at the lowest steam pressure that will heat the building. This may be considerably less than 1 psi on the boiler-pressure gauge. Large buildings may need higher steam pressures, but smaller ones can operate at small steam pressure. Traps and air vents are crucial to operating at a low steam pressure. Electric vent dampers will reduce off-cycle losses for both gas- and oil-fired systems.



One-pipe and two-pipe steam systems: Still common in multifamily buildings, one-pipe steam works best when very low pressure steam can drive air out of the piping and radiators quickly through plentiful vents. Vents are located on each radiator and also on main steam lines.



Two-pipe steam systems: Radiator traps keep steam inside radiators until it condenses. No steam should be present at the condensate tank.

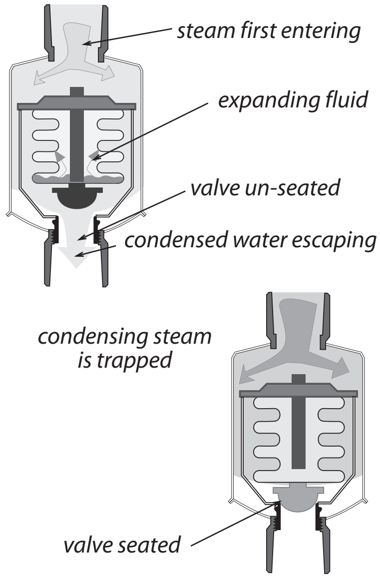
Perform the following for safety and maintenance checks on steam systems.

- ✔ Verify that steam boilers are equipped with high-pressure limits and low-water cut-off controls.
- ✔ Verify that flush valves on low water cut-offs are operable and do not leak.
- ✔ On steam boilers with externally mounted low water cutoffs, verify the function of the control by flushing the low water cutoff with the burner operating. Combustion must cease when the water level in the boiler drops below the level of the float.
- ✔ Drain water out of blow-down valve until water runs clear.
- ✔ Check with owner about chemicals added to boiler water to prevent corrosion and mineral deposits. Add chemicals if necessary.
- ✔ Ask owner about instituting a schedule of blow-down and chemical-level checks.

Consider the following efficiency checks and improvements for steam systems.

- ✔ Verify that high-pressure limit control is set at or below 1 (one) psi.
- ✔ Inspect return lines and condensate receiver for steam coming back to the boiler. Check radiator and main line traps.
- ✔ Verify steam vents are operable and that all steam radiators receive steam during every cycle. Unplug vents or replace malfunctioning vents as necessary. Add vents to steam lines and radiators as needed to achieve this goal.
- ✔ Check steam traps with a digital thermometer or listening device to detect any steam escaping from radiators through the condensate return. Replace leaking steam traps or their thermostatic elements.
- ✔ Consider installing remote sensing thermostats that vary cycle length according to outdoor temperature and include night-setback capability.

- ✔ Repair leaks on the steam supply piping or on condensate return piping.



Steam traps: Steam enters the steam trap heating its element and expanding the fluid inside. The expanded element plugs the steam's escape with a valve.

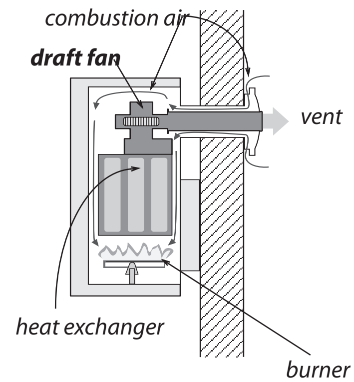
- ✔ Consider a flame-retention burner and electric vent damper as retrofits for steam boilers.
- ✔ Clean fire side of heat exchanger of noticeable dirt.
- ✔ All steam piping, passing through unconditioned areas, should be insulated to at least R-3 with fiberglass or specially designed foam pipe insulation rated for steam piping.

Boiler replacement

Don't assume that a boiler replacement will save much energy unless the boiler's steady-state efficiency can't be raised to around 80%. The overall goal of boiler replacement is to provide a hydronic heating system in virtually new condition, even though existing supply and return piping may remain. Any design flaws in the venting, piping, and controls should be diagnosed and corrected during the boiler replacement.

Boiler piping and controls present many options for zoning, boiler staging, and energy-saving controls. Dividing homes or multifamily buildings into zones, with separate thermostats, can significantly improve energy efficiency over operating a single zone. Modern hydronic controls can provide different water temperatures to different zones with varying heating loads.

The new boiler should have an AFUE of at least 80%. The new boiler should be equipped with electronic ignition and a draft-assisting or power-draft fan. It should not have a draft diverter.



Wall-hung boiler: Energy-efficient wall-hung boilers require less space than standard boilers.

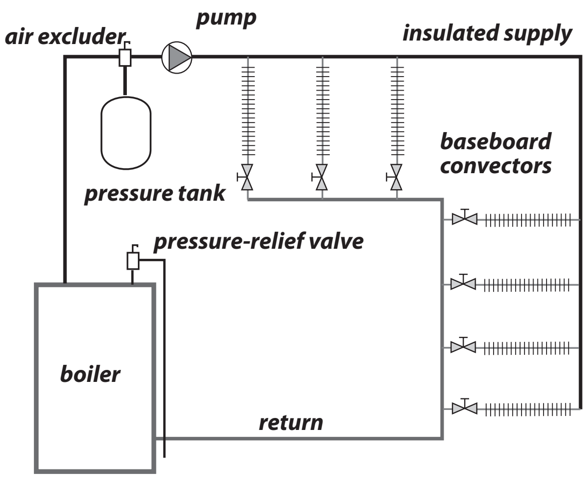
Boiler seasonal efficiency is more sensitive to proper sizing than is furnace efficiency. A boiler should not be oversized by more than 15%.

Follow these specifications when replacing boilers.

- ✔ Inspect chimney for deterioration and correct sizing. Repair and re-line the chimney as necessary.
- ✔ An effective air-excluding device or devices must be part of the new hydronic system.
- ✔ Install the pump near the downstream side of the pressure tank to prevent the suction side of the pump from depressurizing the piping, which can pull air into the piping.
- ✔ The pressure tank should be replaced, unless it is verified to be the proper size for the new system and tested for correct pressure during boiler installation.
- ✔ Verify that return water temperature is above 130° F for gas and above 150° F for oil, to prevent acidic condensation within the boiler, unless the boiler is designed for condensing. Install piping bypasses, mixing valves, primary-secondary piping, or other strategies, as necessary, to prevent condensation within a non-condensing boiler.

✔ Recognize the boiler installation's potential for causing condensation in the vent connector and chimney. If the boiler's steady-state efficiency is expected to be more than 83%, condensation-resistant venting and condensation drains should be designed into the venting system. These custom venting systems are provided or specified by the manufacturer.

✔ A pressure-relief valve must be installed with the new boiler and connected to a drain pipe, draining into a floor drain.

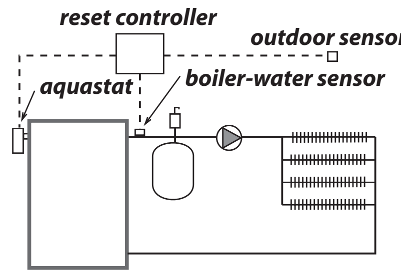


Simple reverse-return hot-water system: The reverse-return method of piping is the simplest way of balancing flow among heat emitters.

✔ Maintaining a low-limit boiler-water temperature is wasteful. Boilers should be controlled for a cold start, unless the boiler is used for domestic water heating.

✔ Insulate all supply piping, outside conditioned spaces, with foam or fiberglass pipe insulation.

✔ Extend new piping and radiators to conditioned areas like additions and finished basements, currently heated by space heaters.



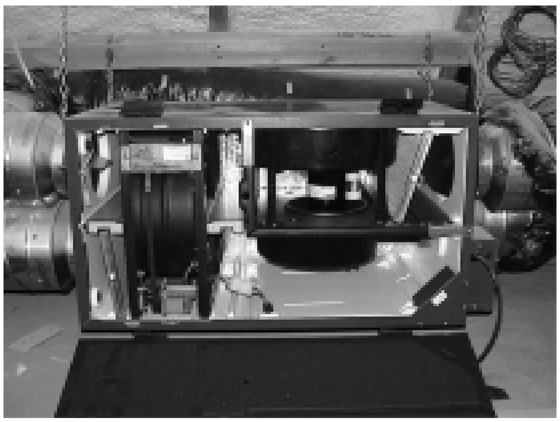
Reset controller: The circulating water is controlled by the reset controller according to the outdoor temperature.

✔ For large boilers, consider installing outdoor reset controllers to adjust supply water temperature according to outdoor temperature.

✔ For large boilers, consider installing a cutout controller that prevents the boiler from firing when the outdoor temperature is above a certain setpoint where heat is not needed.

3.10 Ventilation Systems

Choose high-quality equipment that has the best sound rating. The noise made by cheap bearings and impeller blades also translates into shorter service life. A well-designed ventilation system is nearly inaudible. Noisy systems are often not used, or worst yet, disabled by occupants.



Quiet installation: This central ventilator is suspended from chains to reduce sound transmission through the home's framing. Short runs of flex duct attenuate fan noise in the duct system. The same standards should be applied to spot ventilators as well.

Ventilation equipment should have a laboratory-measured sound rating that is included in the manufacturer's literature or stamped on the unit. These ratings are specified in *sones*. A quiet refrigerator, for example, produces about 1.0 sone. The best bathroom fans produce 0.5 to 1.5 sones, though many consumer-grade fans produce 3.0 to 4.0 sones. Range hoods vary from 4.0 to 8.0 sones. Many codes and standards specify a maximum noise rating of 1.0 to 2.0 sones for surface mounted fans because their sound travels directly into the living space. Remotely mounted fans and central ventilators can produce more noise at the unit without disturbing occupants.

Provide flexible mountings for ventilating equipment and nearby ducts to reduce vibration and noise. Mount them so they don't touch framing members if possible. Use vibration isolating pads, gaskets, or straps where contact is unavoidable.

Install flexible plenum boots at central ventilation, heating, and cooling equipment.

Install metal ducting whenever possible. Insulated flex duct or duct board creates resistance to airflow that reduces efficiency. Metal duct is also easier to clean, and is resistant to the growth of bio-contaminants. Short runs of flex duct may be acceptable if needed to overcome installation obstacles.

Do not use building cavities as ducts. They always leak conditioned air, and often introduce pollutants into the airstream.

When installing manually controlled exhaust fans in bathrooms or kitchens, install backdraft dampers on ducts that run to the exterior. This will reduce the intrusion of cold air and possible condensation during the off-cycle. Even if the equipment includes a damper, it is a good idea to install one at the exterior termination hood.

Spot Ventilation

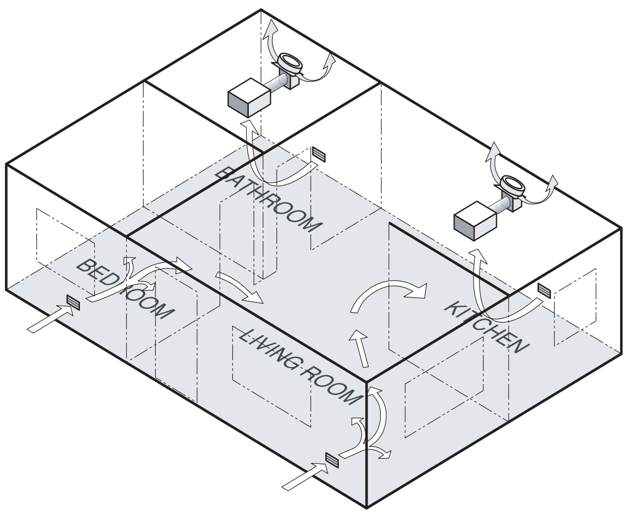
Exhaust-only systems remove pollutants at the source and exhaust them to the outdoors. They have been used in the majority of ventilation systems over the years because they are inexpensive to install and work reasonably well in poorly sealed buildings.

Exhaust systems create areas of low pressure within the home, drawing air in through leaks in the shell or through passive inlets. This keeps moist indoor air from traveling into building cavities, reducing the likelihood of moisture accumulation in cold climates. In hot and humid climates, however, this depressurization can draw outdoor moisture into the home.

Exhaust-only ventilation usually incurs an energy penalty as conditioned air–whether heated, cooled, or de-humidified–is lost to the outdoors.

Exhaust fans are sometimes used in conjunction with balanced whole-house ventilation systems that serve an entire building. This spot ventilation can reduce the requirements of the central system by removing some pollutants before they mingle with air in the rest of the home. This combination of spot ventilation and whole-house ventilation is specified in many ventilation standards.

Exhaust fans should be ducted to the outdoors, and not into an attic or crawl space where moisture and pollutants can accumulate. Install a backdraft damper to reduce cold air intrusion when the system is not operating. The damper can be integral to the fan unit as provided by the manufacturer, installed separately in the exhaust duct, or included at the roof or wall termination hood.



Local Exhaust Fans: Individual fans exhaust air to the outdoors from rooms where pollutants are produced.

Room exhaust fans are most effective when installed close to the source of pollutants. Bath fans, for example, should be located near the shower if possible. Kitchen fans should be installed close to the range.

Condensation in fans and ducting is always a concern in cold climates. Attic and vaulted ceiling installations are the trickiest, since the fan and ducting tend to displace insulation and create cold spots that encourage duct condensation.

Install exhaust fans and ducting as close as possible to the heated space, which usually means against the sheetrock. Avoid long duct runs, especially where they are above the insulation. Use foam insulation if needed to minimize heat loss from exhausted air.

Avoid the use of recirculating or ductless range hoods. These may have filters that collect odors and grease, but the filter often clogs or becomes ineffective in short order. And they don't remove moisture.

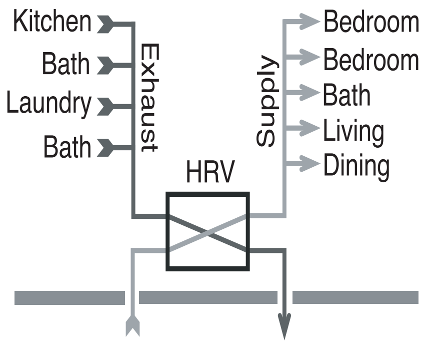
Whole house ventilation systems

Balanced ventilation systems provide measured fresh air via planned pathways. Of all the ventilation schemes, they do the best job of controlling pollutants in the home.

Balanced systems move equal amounts of air into and out of the home. Most balanced systems incorporate heat recovery ventilators that reclaim some of the heat and/or moisture from the exhaust air stream. Simple mixing boxes are occasionally used to temper incoming air by mixing it with exhaust air, but their cost approaches that of heat recovery ventilators, and they incur a large energy penalty as conditioned air is lost to the outdoors.

Balanced systems, when operating properly, reduce many of the safety problems and moisture-induced building damage that is possible with unbalanced ventilation. They are not trouble-free, however, and there are many homes with "balanced" ventilation systems that experience pressure imbalances and poor air quality due to poor design, installation, or maintenance.

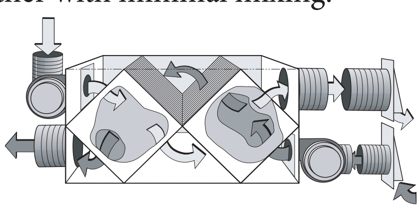
These complicated systems can improve the safety and comfort of home, but a high standard of care is needed to assure that they operate properly. Testing and commissioning is vital during both the initial installation and periodic service calls.



Fully-Ducted Central Ventilator : Fully ducted systems do the best job of collecting pollutants. They are installed independently of heating and cooling systems, and work well in homes with hydronic or electric baseboard heat where no ducting is installed.

Heat recovery ventilators

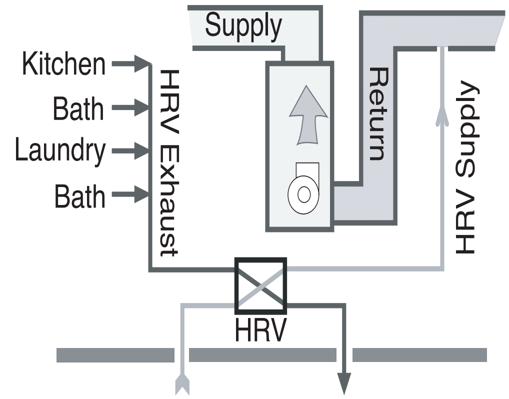
Heat recovery ventilators (HRVs) are often installed in conjunction with balanced whole-house ventilation systems. The HRV core is usually a *flat-plate* aluminum or polyethylene air-to-air heat exchanger in which the supply and exhaust airstreams pass one another with minimal mixing.



HRV Air Paths: Exhaust and supply airstreams pass one

Heat travels through the core, by conduction, from the warmer to the cooler airstream. In heating climates this means that heat contained in the exhaust air warms the incoming supply air. In cooling climates, the heat of the incoming supply air is passed to the outgoing exhaust. Either transfer reduces the energy loss incurred by ventilation.

In cold climates, outgoing moisture will tend to condense when it passes the cold incoming air in the HRV core. This condensate is collected and carried to a drain. Defrost mechanisms are needed in severe climates to prevent the condensate from freezing when it meets frigid outdoor air in the heat exchanger. The most economical defrost method is periodic recirculation of warm indoor air, though some HRVs with aluminum cores use electric heat strips.



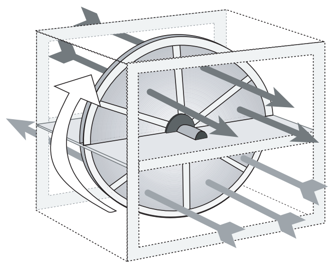
Exhaust-Ducted Central Ventilator: Dedicated ducting collects pollutants at the source. Fresh air is introduced to either the return or supply plenum.

Energy recovery ventilators

Energy recovery ventilators (ERVs) work like an HRV but can also transfer moisture from one air stream to the other. A permeable *rotary core* rotates through both airstreams transferring heat and moisture. The core is usually made of plastic or paper, and may incorporate desiccants that aid in moisture transfer. The permeability of rotary cores allows a cross-leakage between airstreams of up to 10%.

In heating climates, where the indoor air is more humid than outdoors, moisture in the core migrates from the humid exhaust stream toward the dry incoming supply air. In cooling climates, wet incoming air is stripped of much of its moisture by the dry exhaust stream. This drying of incoming air reduces the load on the cooling system. ERVs should not be relied upon, however, to control large amounts of moisture from extremely humid indoor environments. Always give precedence to the reduction of moisture sources in these cases.

ERVs do not require a drain. This makes them a good choice for installation in spaces where it is not practical to install a drain line such as upstairs closets or heated attics.



Rotary ERV Core: Exhaust and supply airstreams exchange both heat and moisture in energy recovery ventilators.

Heat Recovery Efficiency Ratings

Apparent Sensible Effectiveness (ASEF) expresses the predicted heat transfer between the exhaust and supply airstreams as they pass through the heat exchanger. The ASEF rating accounts only for the sensible heat transfer across the exchanger, and does not include the parasitic losses included in SRE rating, or the latent heat carried by moisture in the air, as in the TRE rating. ASEF ratings are most useful for sizing systems since they predict the final delivered temperature of the air delivered to the living space at a given flow rate. ASEF ratings vary from 60 to 95%, and will always be higher than the other ratings.

Sensible Recovery Efficiency (SRE) is useful for comparing energy performance of various HRVs since it takes into account sensible heat transfer, effects of cross-leakage, electricity for fan and controls, as well as defrost systems. SRE is lower than ASEF, and typically ranges from 60 to 70 percent at 32˚F, dropping to as low as 44 percent at -13˚F for systems that use electric defrost.

Total Recovery Efficiency (TRE) accounts for all the factors included in SRE, but also considers the latent heat reclaimed by ERVs as moisture is transferred across the air streams. It is useful for comparing performance in cooling climates where the management of moisture is an important factor.

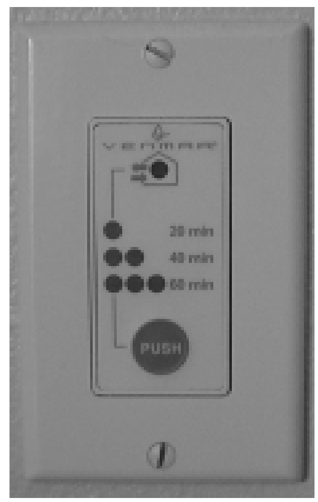
VENTILATION CONTROLS

Controls also provide an opportunity to adjust the system performance over time. A periodic review of the control scheme should be performed, perhaps during service visits, to assure that the system is providing sufficient fresh air for occupants and acceptable moisture control for the building.

Locate the controls in a representative location on a main floor interior wall, and about 60 inches above the floor. Don't install them on an exterior wall, in a drafty location, or in direct sunlight.

Manual control

Simple on/off manual controls allow occupants to ventilate as needed. These are often used for exhaust fans in bathrooms and kitchens. Their effectiveness relies on the user's perception of air quality.



Manual controls: This count-down control allows uses to choose a run-time depending upon their current ventilation needs. Manual controls can be used with both spot ventilators, and as an override control for central systems.

Manual controls sometimes include count-down or time-delay timers that are activated by occupants and run for a specific period of time. In non-owner occupied homes or other situations where occupant cooperation is unlikely, fan-delay timers can be run in conjunction with bathroom lights to give a set period of ventilation whenever the bathroom lights are used.

Humidity control

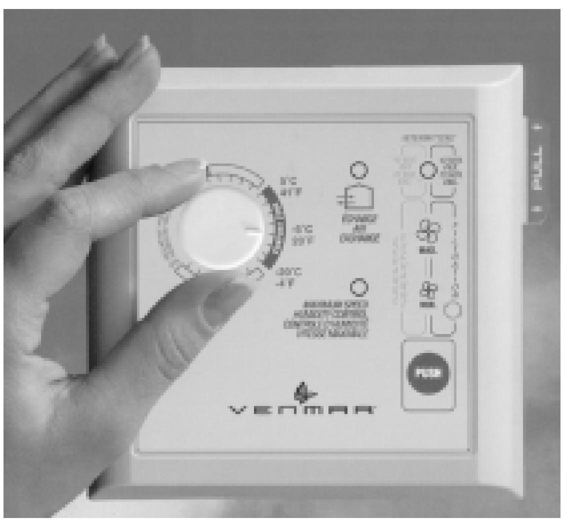
Dehumidistats operate equipment based upon indoor humidity levels. They are used with either simple exhaust fans or central ventilation equipment.

Dehumidistats can be set for a range of humidity levels, and have the advantage of automatic operation that doesn't require much occupant management. They should be set to keep indoor humidity low enough to prevent indoor condensation in the winter. This will vary from 30-50% RH, depending upon the outdoor temperature, effectiveness of windows and insulation, and other factors.

In humid-summer climates, it may be impossible to achieve this level when the outdoor humidity exceeds the RH setting. This can cause the system to run continuously in a futile attempt to dry the incoming moist outdoor air. In these regions, the occupant should either re-set the dehumidistat to a higher RH in the summer, or override it altogether until winter.

Combination controls

Central ventilation systems are often operated by a combination of manual and automatic controls. The most common strategy utilizes a multi-speed fan that runs on low- or medium-speed to provide continuous ventilation. Over-ride switches in the kitchen and bathrooms activate high-speed operation to provide intermittent high-speed operation during pollutant-producing activities such as cooking, bathing, or cleaning. The total airflow requirement specified by ventilation standards refers to this high-speed operation.



Combination control: This control operates a central ventilators based upon humidity, time interval, or manual override.

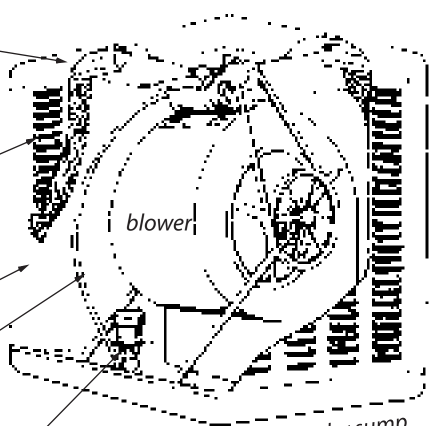
Timers allow the low-speed operation to be set for variable intervals such as 20 minutes on/40 minutes off per hour, 30 on/30 off, or whatever total ventilation time is needed. This adjustable interval provides an effective method of matching the ventilation capacity to the occupants' needs.

3.11 EVAPORATIVE COOLERS

Evaporative coolers (also called swamp coolers) are energy efficient cooling strategy in dry climates. An evaporative cooler is a blower and wetted pads installed in a compact louvered air handler.

Evaporative coolers employ different principles from air conditioners because they reduce air temperature without actually remove heat from the air. They work well only in climates where the summertime relative humidity remains less than 50%. They compare in performance to an air conditioner with a SEER between 30 and 40, which is 2 to 3 times the SEER of the most efficient air conditioners.

An evaporative cooler can be mounted on a roof, through a window or wall, or on the ground. The cooler can discharge air directly into a room or hall or it can be connected to ducts for distribution to numerous rooms.



EVAPORATIVE COOLER OPERATION

The evaporative cooler's blower moves air through water-saturated pads. Water evaporates into the incoming air, reducing its temperature. This cooler-than-indoors air is blown into the house by the blower, pushing warmer air out through open windows or dedicated up-ducts.

A water pump in the reservoir circulates water through tubes into a drip trough, which then drips water onto the pads. A float valve connected to the home's water supply keeps the reservoir supplied with fresh water to replace the water evaporated.

Air circulation: Outdoor air is sucked through the evaporative cooler and blown into the home pushing house air out the partially open windows.

Opening windows in occupied rooms, and closing windows in unoccupied rooms concentrates the cooling effect where residents need it. Open the windows or vents on the leeward side of the home to provide approximately1 to 2 square feet of opening for each 1,000 cfm of cooling capacity. Experiment to find the right windows to open and how wide to open them. If the windows are open too wide hot air will enter. If the windows are not open far enough humidity will rise, and the air will feel sticky.

EVAPORATIVE COOLER SIZING AND SELECTION

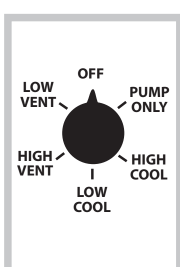
Evaporative coolers are rated in cubic feet per minute (cfm) of airflow they deliver. Airflow capacity ranges from 2000 to 7,000 cfm. Recommendations vary from 2-to-3 cfm per square foot of floor space for warm dry climates and 3-to-4 cfm/sf for hot desert climates.

EVAPORATIVE COOLER INSTALLATION

Evaporative coolers are installed in two ways: the cooler outlet blows air into a central location, or the cooler outlet joins ductwork which distributes the cool air to different rooms in the house. Single outlet installations work well for compact homes. Ducted systems work better for more spread-out homes.

Most people install down-flow evaporative coolers on the roofs of their homes. Evaporative coolers are also installed on stands or hung on platforms. These coolers vent their cool air through windows or ducts cut through walls. Some horizontal ducted evaporative coolers are ground-mounted on concrete pads for easy access. The best place for a horizontal-flow evaporative cooler is in the shade on the windward side of the home. Observe the following basic installation specifications.

- ✔ The cooler should have a fused disconnect and water shutoff nearby.
- ✔ The cooler should have at least 3 feet of clearance all around them for airflow and maintenance access.
- ✔ Installing the cooler with weighted dampers allows easier changeover from evaporative cooling and either heating or air conditioning.
- ✔ Using thermostats to control evaporative coolers minimizes energy use, water use, and maintenance. Thermostats also reduce the chance of over-cooling with unnecessary nighttime operation. Using a 24-volt transformer and thermostat is better than using a line-voltage thermostat, which allows more temperature variation.
- ✔ Evaporative coolers often have two speeds for cooling or venting. The vent settings activate the blower but not the pump, to use the cooler as a whole-house fan at night and during mild weather.
- ✔ Selecting a control equipped with a pump-only setting, permits flushing dirt out of the pads before activating the blower after the cooler has been off for days or weeks.



Deluxe cooler control: Controls like this allow greater comfort in a variety of summer weather conditions. These controls work best in cooperation with a thermostat.

- ✔ Choose a cooler that has a bleed tube or sump pump to drain dirty water from the sump.

Evaporative coolers produce high air flows; the ductwork connected to them should be sized appropriately. The cooler's supply outlet can supply one or more registers through a dedicated duct system. Or, the supply outlet can connect to ducts that join to furnace or air conditioner ducts.

Coolers sharing ducts with forced-air furnaces require dampers to prevent heated furnace air from blowing into the idle evaporative cooler during the winter, and prevent moist cool air from blowing into the furnace during the summer. Moist cool air can condense and cause rust inside the furnace. These shared systems must be installed with great care. The dampers often stick in an open position even with careful installation.

Up-ducts are ceiling vents that exhaust warm air as the evaporative cooler pushes cooler air in. Up-ducts are preferred by home owners who don't like leaving windows open for security or privacy reasons. Up-ducts also help maintain a positive pressure in the home, preventing wind-driven hot air from entering through open windows. It is essential to have adequate attic ventilation when using up-ducts. Attic vents should have 1 to 1.5 times the net free area of the up-ducts.

Evaporative cooler maintenance

Evaporative coolers see a lot of water, air, and dirt during operation. Dirt is the enemy of evaporative cooler operation. Evaporative coolers process a lot of dirt because their aspen pads are good filters for dust-bearing outdoor air. Evaporative coolers may cool better and filter better when the aspen pads are doubled up.

Airborne dirt that sticks to the cooler pads washes into the reservoir. Most evaporative coolers have a bleed tube or a separate pump that changes the reservoir water during cooler operation to drain away dirty water. A cooler may still need regular cleaning, depending on how long the cooler runs and how well the dirt-draining system is working. Be sure to disconnect the electricity to the unit before servicing or cleaning it.

Older cooler sumps were lined with an asphaltic paint and flexible asphaltic liners, but the newer ones have factory powder coatings that are far superior and less environmentally harmful. Don't paint or install asphaltum liners in a powder-painted cooler sump because asphaltic material won't stick to the factory finish.

Observe these general specifications for maintaining evaporative coolers.

- ✔ Aspen pads can be soaked in soapy water to remove dirt and then rotated to distribute the wear, dirt, and scale, which remains entrained after cleaning. Clean louvers in the cooler cabinet when you clean or change pads. Replace the pads when they become unabsorbent, thin, or loaded with scale and entrained dirt.

Table 3.11.1: Cooling Potential for Evaporative Coolers

Outdoor Temperature F°	Outdoor Relative Humidity %														
	2	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
75	54	55	57	58	59	61	62	63	64	65	66	67	68	69	70
80	57	58	60	62	63	64	66	67	68	71	72	73	74	76	76
85	61	62	63	65	67	68	70	71	72	73	74	75	76	77	79
90	64	64	67	69	70	72	74	76	77	78	79	81	82	83	84
95	67	68	70	72	74	76	78	79	81	82	84	85	87		
100	69	71	73	76	78	80	82	83	85	87	88				
105	72	74	77	79	81	84	86	88	89						
110	75	77	80	83	85	87	90	92							
115	78	80	83	86	89	91	94								
120	81	83	86	90	93	95									
125	83	86	90	93	96										

An evaporative cooler with good pads and adequate airflow should give the temperatures listed here, depending on outdoor temperature and relative humidity.

- ✔ If there is a bleed tube, check discharge rate by collecting water in a cup or beverage can. You should collect a cup in three minutes or a can in five minutes.
- ✔ If the cooler has two pumps, one is a sump pump. It should activate to drain the sump every five to ten minutes of cooler operation.
- ✔ If there is any significant amount of dirt on the blower's blades, clean the blower thoroughly. Clean the holes in the drip trough that distributes the water to the pads.
- ✔ The reservoir should be thoroughly cleaned each year to remove dirt, scale, and biological matter. You can gather silt and debris using two old hand towels or rags working together from the corners of the sump pushing the dirt and silt into the sump drain or into a bucket.
- ✔ Pay particular attention to the intake area of the circulating pump during cleaning.

Debris can get caught in the pump impeller and stop the pump.

- ✔ Check the float assembly for positive shut-off of water when the sump reaches its level. Repair leaks and replace a leaky float valve.
- ✔ Investigate signs of water leakage and repair water leaks.

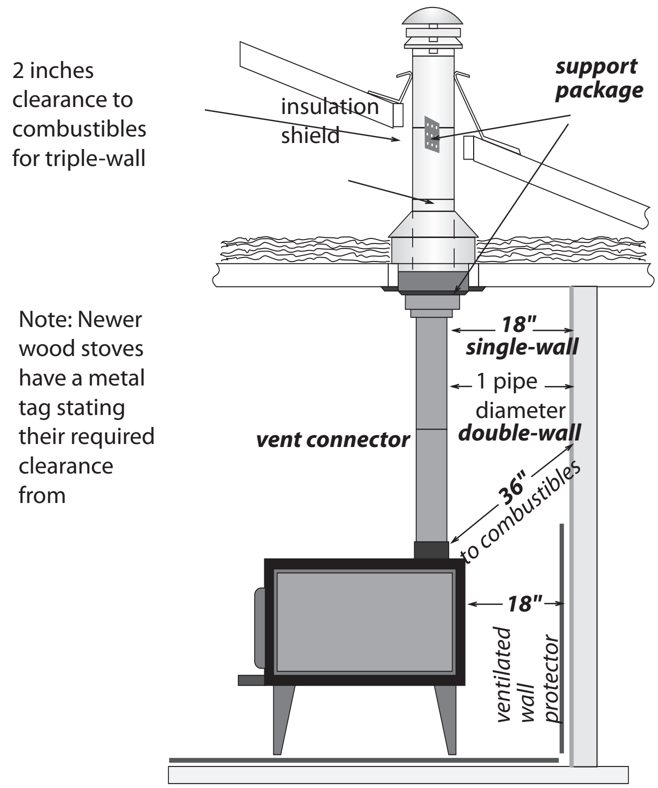
3.12 Wood-stove Venting and Safety

Wood heating is a popular and effective auxiliary heating source for homes. However, wood stoves and fireplaces can cause indoor-air-pollution and fire hazards. It's important to inspect wood stoves to assess potential hazards.

Stoves that are listed by a testing agency like Underwriters Laboratory have a tag stating their clearance from combustibles. Unlisted stoves should conform to the minimum clearances shown here. Ventilated wall protectors, described in NFPA codes and standards, generally allow the listed clearance to be reduced by half. *See section 3.2.*

All components of wood-stove venting systems should be approved for use with wood stoves. Chimney sections penetrating floor, ceiling, or roof should have approved thimbles, support packages, and ventilated shields to protect combustible materials from high temperatures.

- ✔ Inspect stove, vent connector, and chimney for correct clearances from combustible materials as listed in NFPA 211. Ensure that stove is sitting on a noncombustible floor.
- ✔ Inspect vent connector and chimney for leaks, and seal leaks with a high-temperature sealant designed for use with metal or masonry.
- ✔ Inspect chimney and vent connector for creosote build-up, and clean chimney if creosote build-up exists.
- ✔ Inspect the house for soot on seldom-cleaned horizontal surfaces. If soot is present or if the blower door indicates leakage, inspect and replace the gasket on the wood-stove door if appropriate. Seal other air leaks, and take steps to improve draft as necessary, in order to reduce indoor smoke emissions.
- ✔ Inspect and clean stack damper and/or combustion air intake if necessary.
- ✔ Check catalytic combustor for repair or replacement if the wood stove has one.
- ✔ Assure that heat exchange surfaces and flue passages within the wood stove are free of accumulations of soot or debris.



Wood-stove installation: Wood-stove venting and clearances are vitally important to wood-burning safety. Read and follow all manufacturer's instructions for the stove and its venting components.